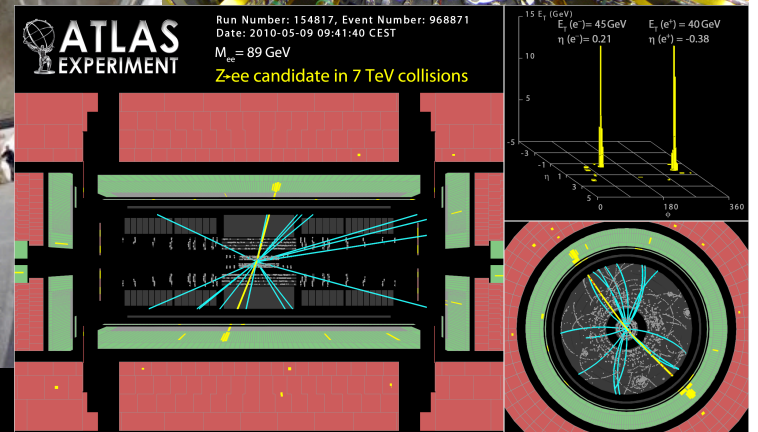
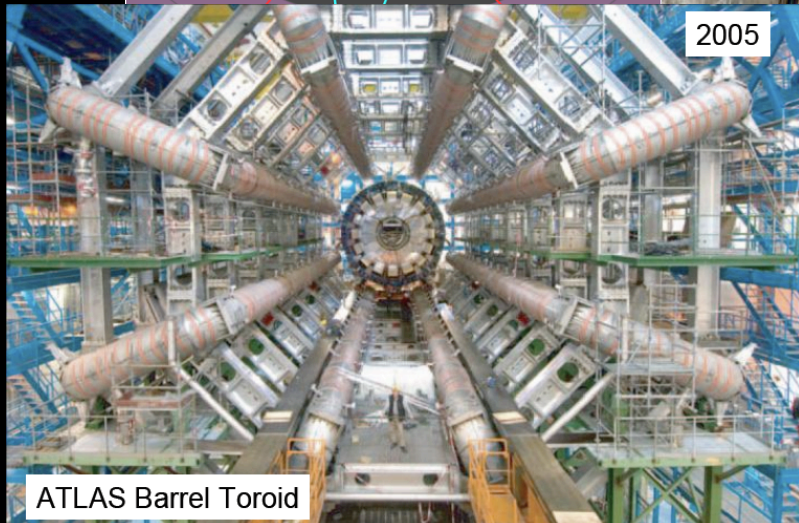
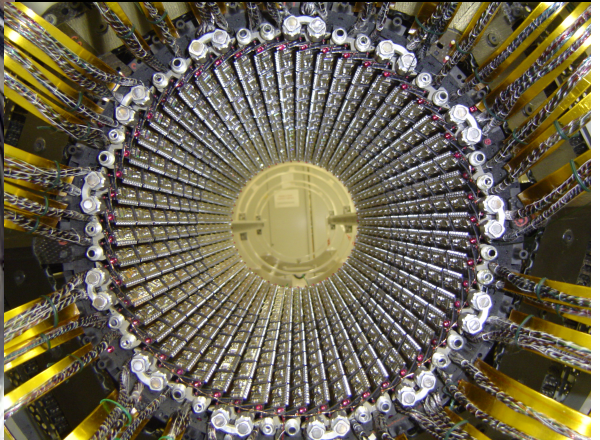
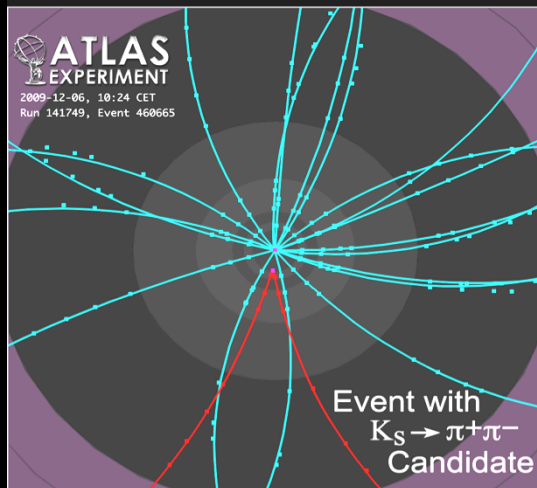


# The ATLAS Experiment at LHC

## Status and First Results



*Beate Heinemann, UC Berkeley and LBNL  
SLUO, SLAC, August 2010*

# Outline

- **Introduction**

- LHC and ATLAS
- Data Taking, Luminosity and Trigger+DAQ

- **First Physics Results**

- Minimum Bias
- J/psi and Upsilon
- Jets
- W's and Z's
- Towards Top
- New Physics



indicates leading  
contribution from  
West Coast institution(\*)

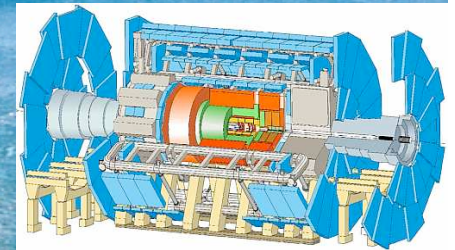
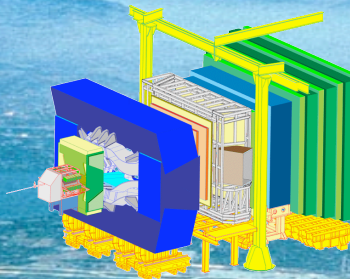
(\*) Arizona, Oregon, SLAC, UCB/LBNL,  
UCSC, UCI, Washington

- **Conclusions and Outlook**

# The Large Hadron Collider (LHC)

*MontBlanc*

*Circumference: 16.5 miles*

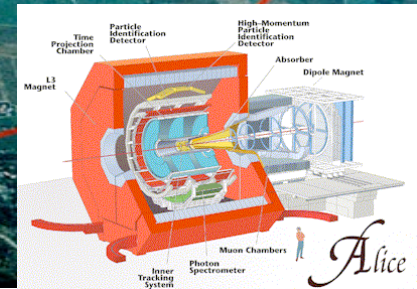
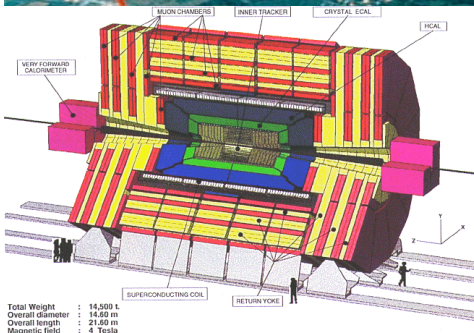


*LHCb*

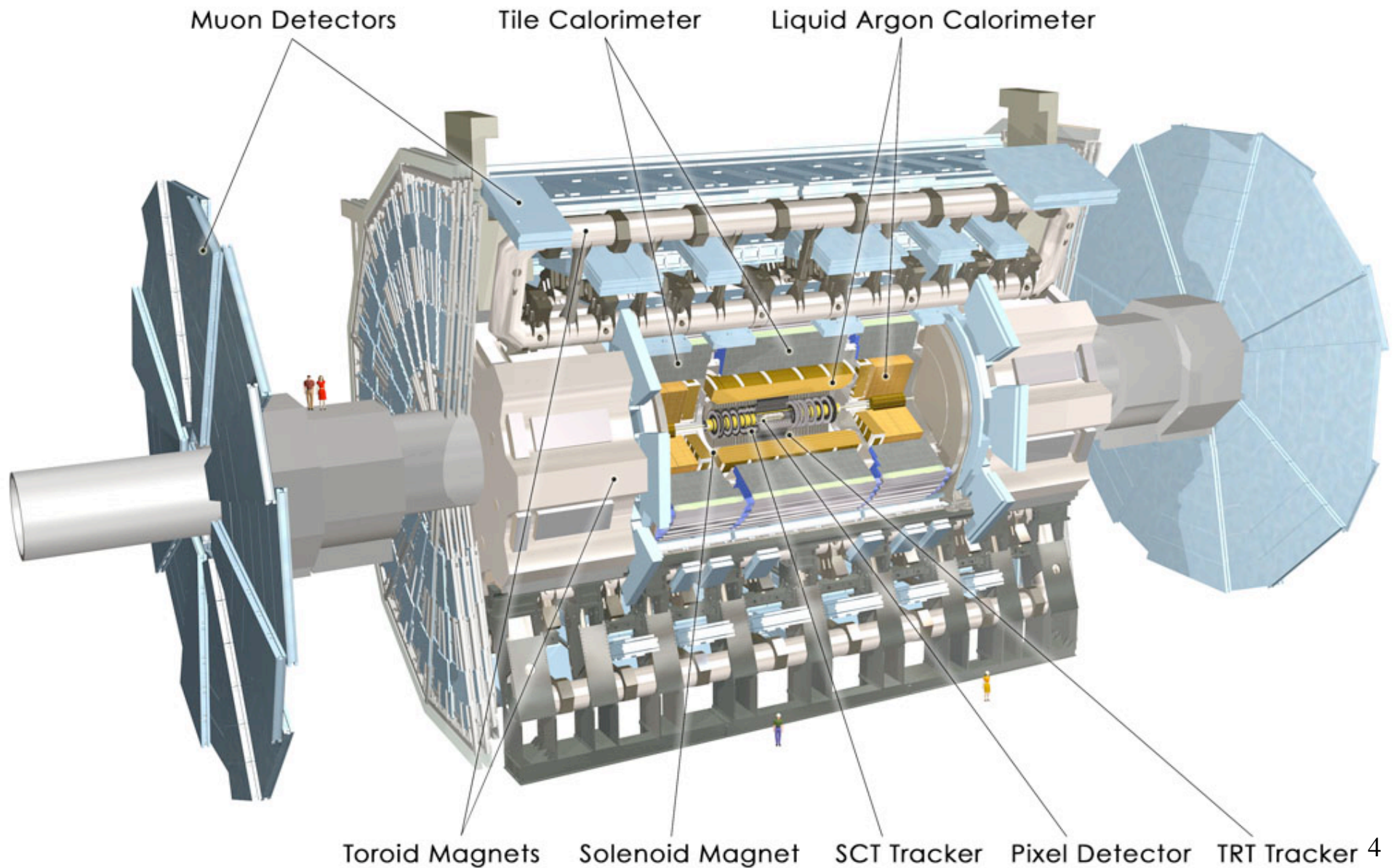
*ATLAS*

*ALICE*

$\sqrt{s}=7 \text{ TeV}$



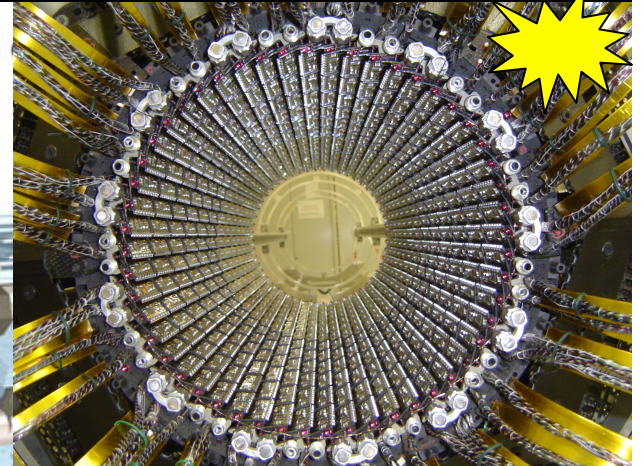
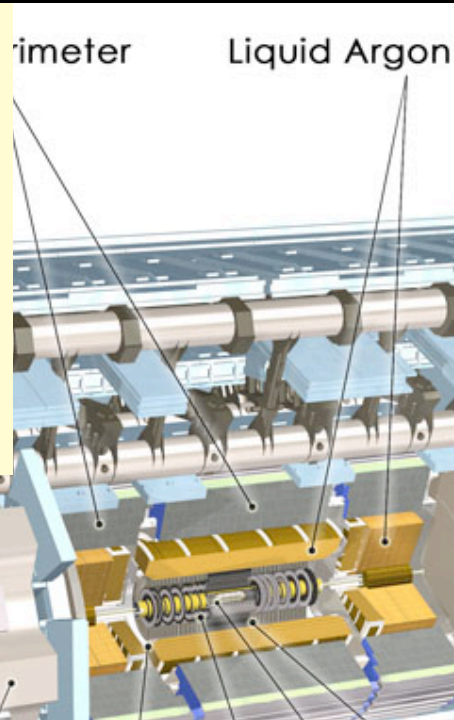
# ATLAS Detector



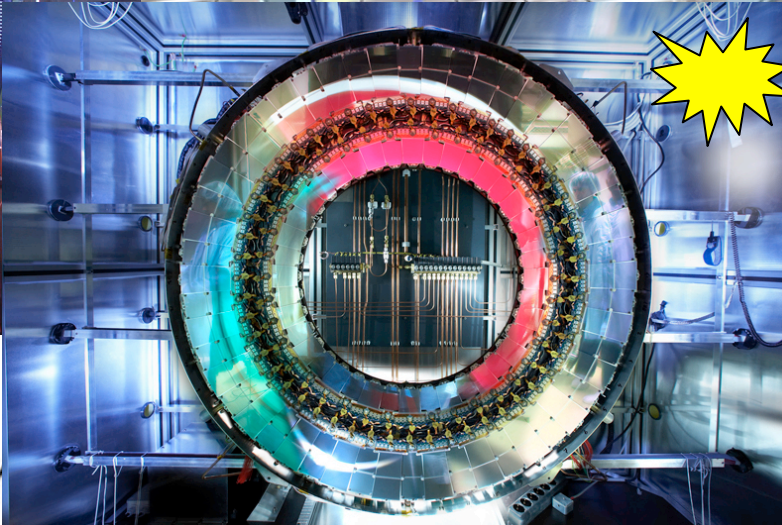
# ATLAS Detector

## Inner Detector: $|\eta| < 2.5$

- Si Pixels:  $40 \times 800 \mu\text{m}$
- Si Strips:  $80 \mu\text{m}$
- Transition Rad. Tracker
- Solenoid:  $B=2 \text{ T}$
- $\sigma/p_T = 3.8 \times 10^{-4} p_T/\text{GeV} \oplus 0.015$   
(e.g. 4% at 100 GeV)



Toroid M



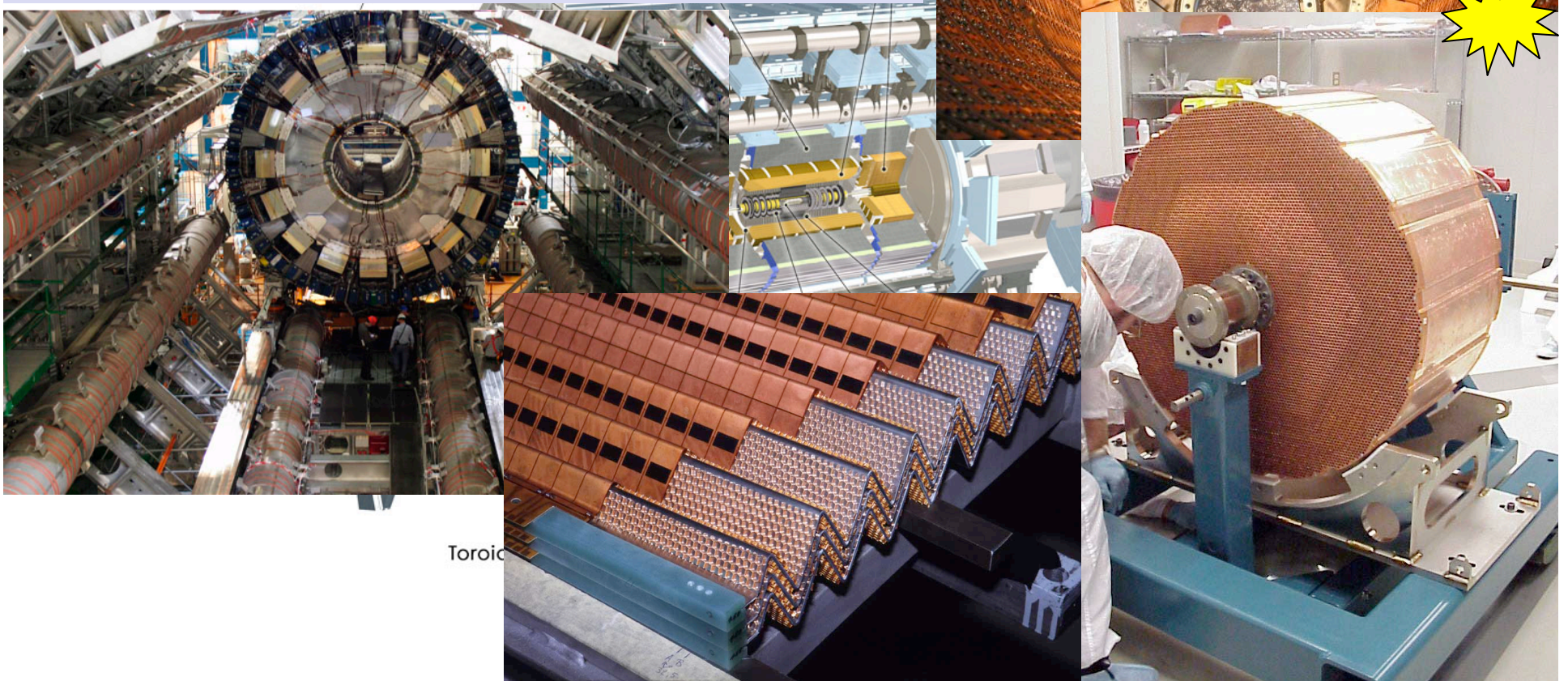
Pixel Detector TRT Tracker 5



# ATLAS Detector

## Calorimeters: $|\eta| < 4.9$

- Lead/LAr : Electromagnetic
- Cu/LAr : Hadronic Endcap
- Tile (steel/plastic scintillator): Hadronic Barrel
- EM:  $\sigma/E = 10\% \sqrt{E}$  (e.g. 1% at 100 GeV)
- HAD:  $\sigma/E = 50\% \sqrt{E} \oplus 3\%$

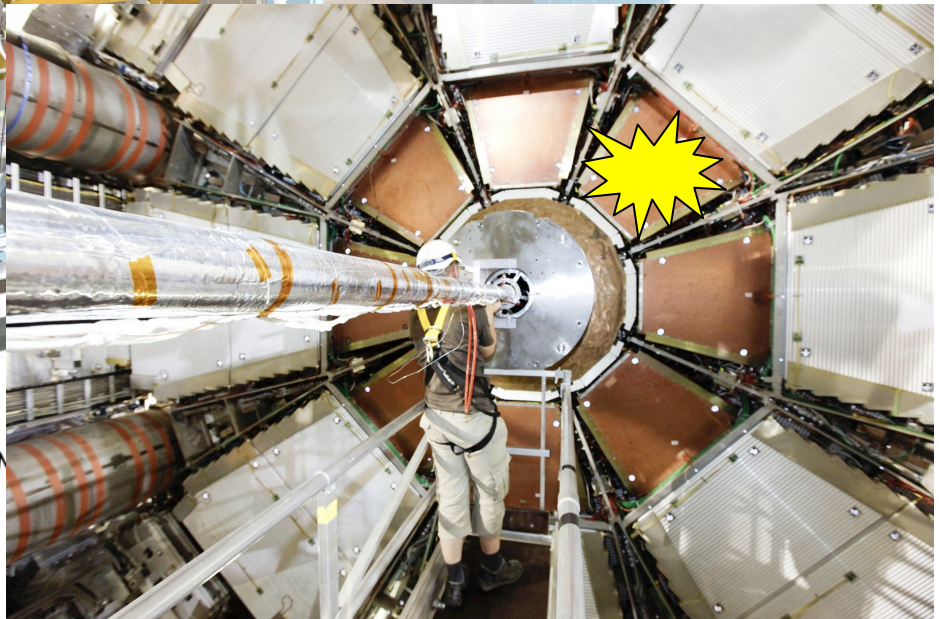
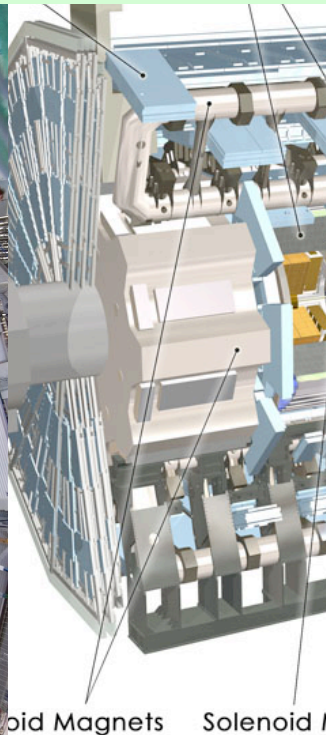
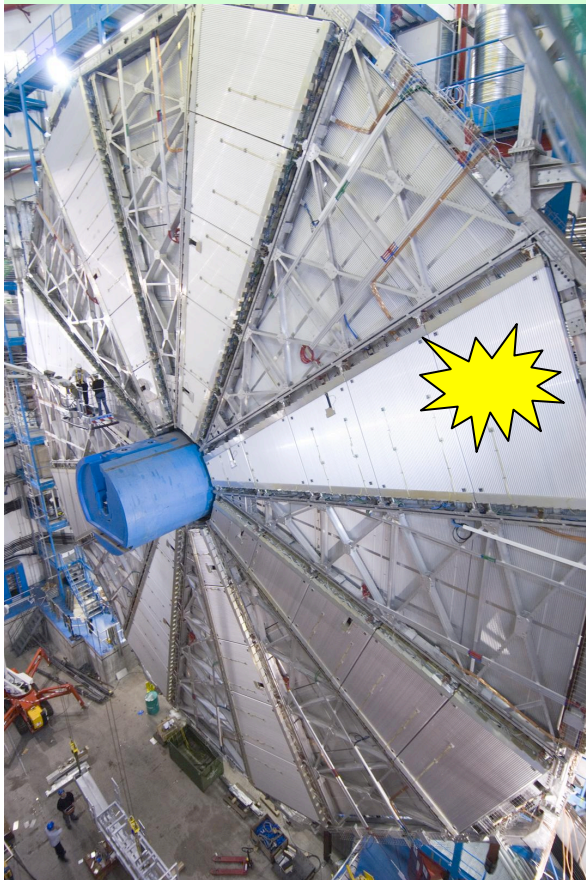
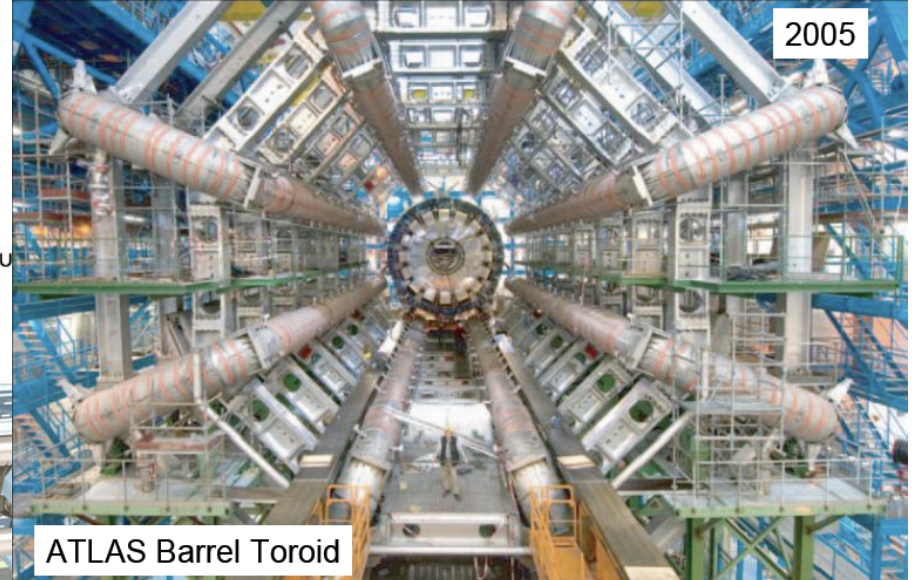


# ATLAS Detector

## Muon System: $|\eta| < 2.5$

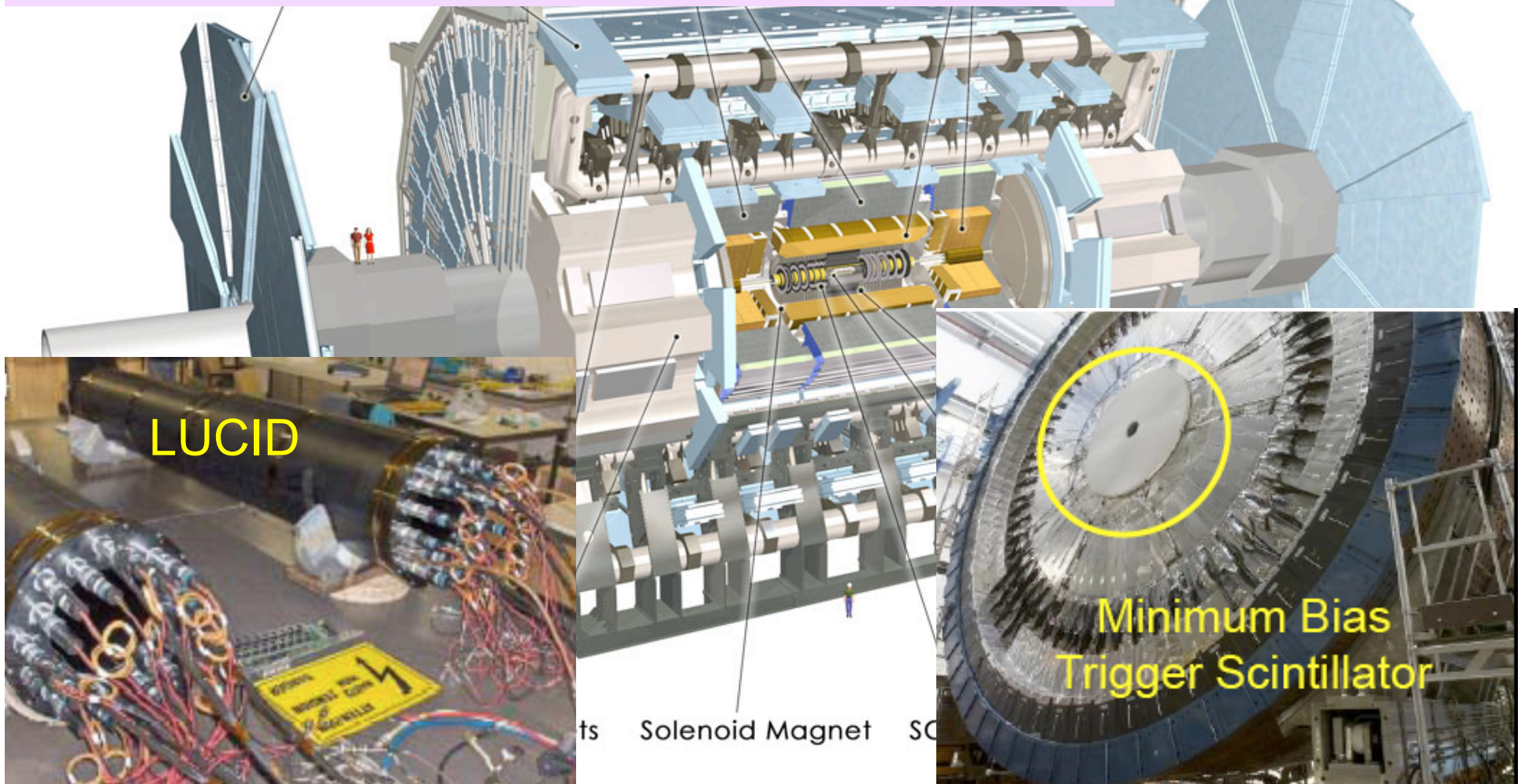
- Precision chambers (MDT and CSC)
- Trigger chambers (RPC and TGC)
- Air-core toroid magnet ( $\int B dL = 1-7.5 \text{ Tm}$ )
- 10%  $p$  resolution at 1 TeV

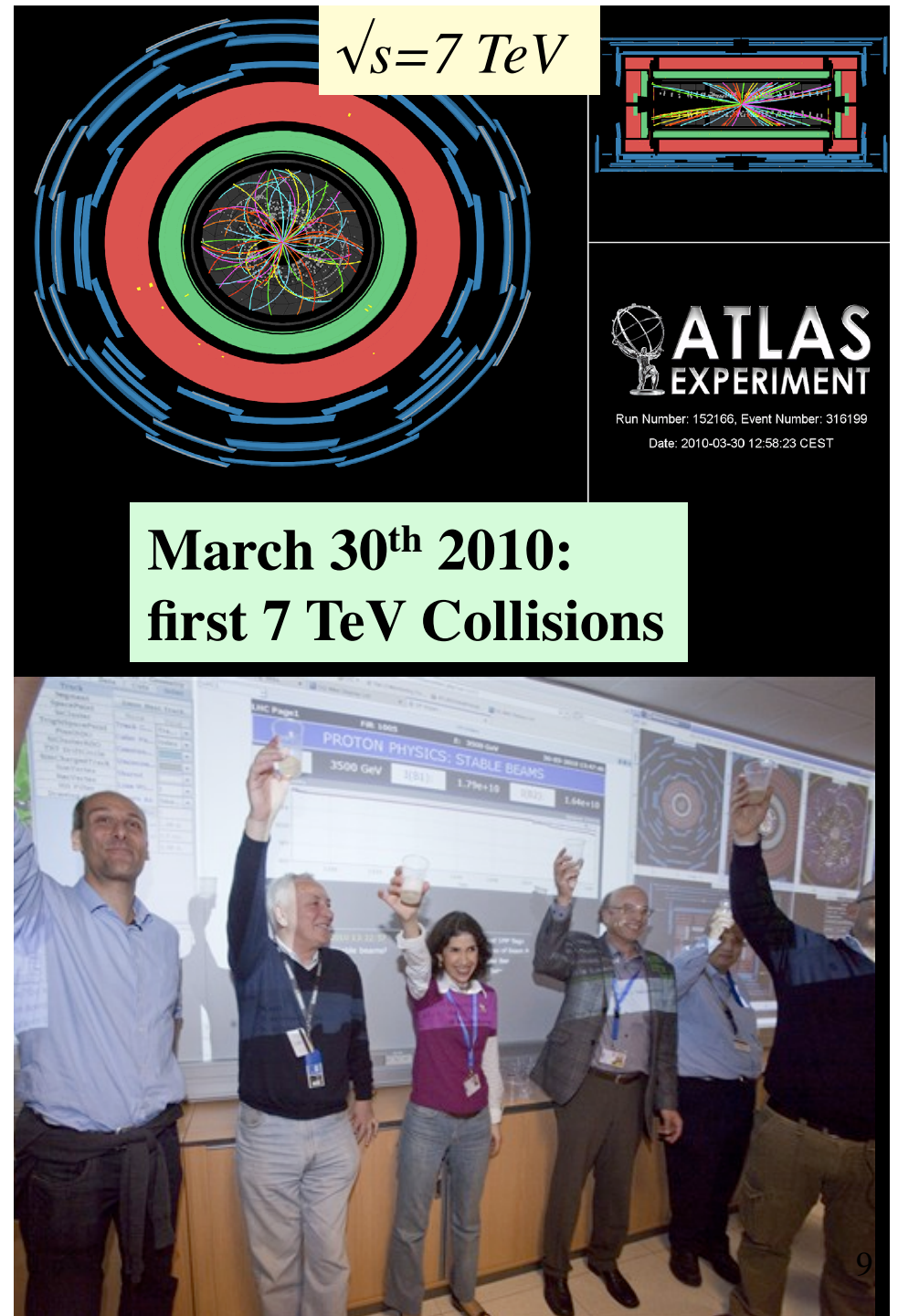
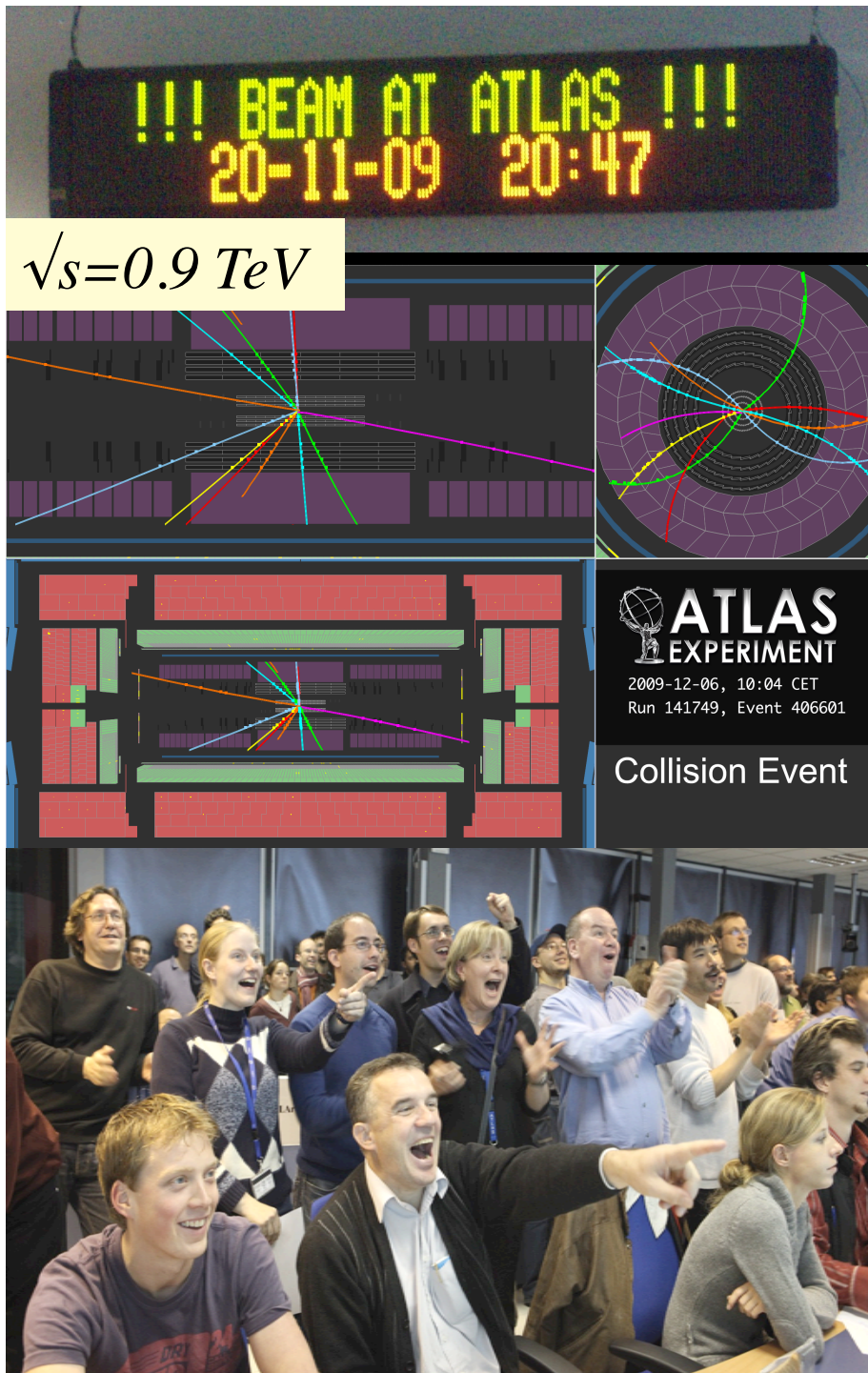
Liqu



# ATLAS Detector

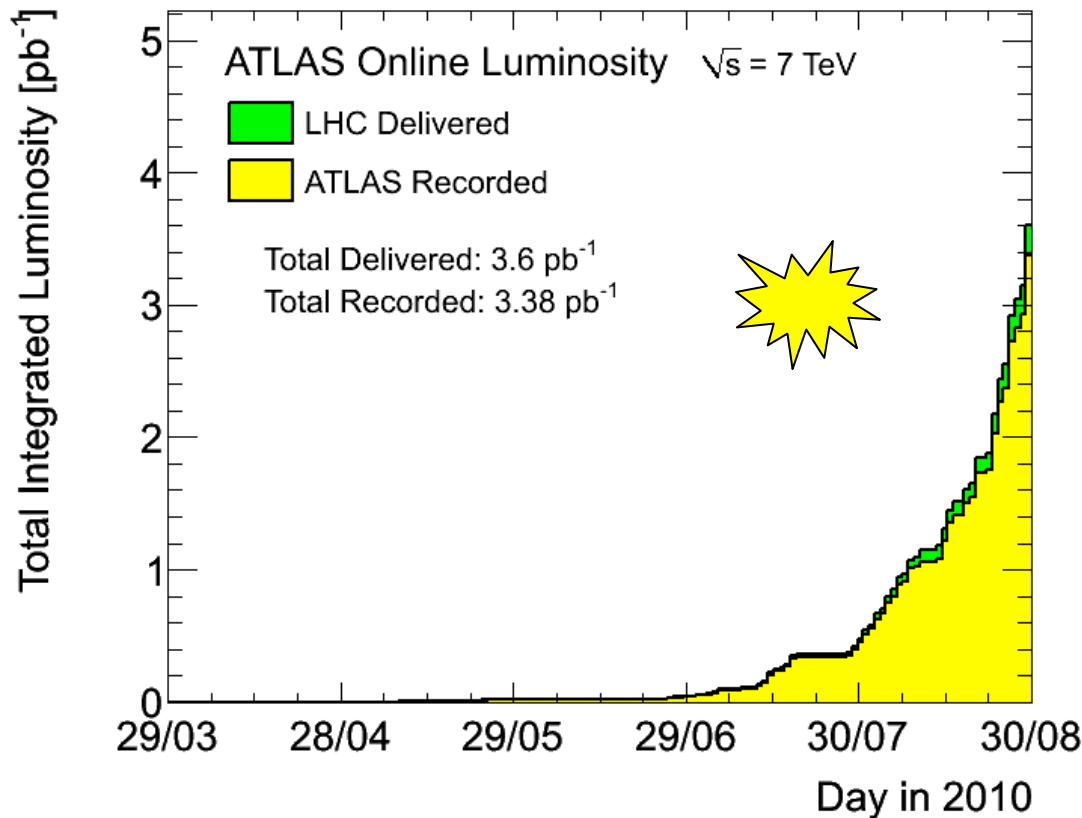
- **Several forward detectors**
  - LUCID, MBTS, ZDC
  - Luminosity measurement and forward physics



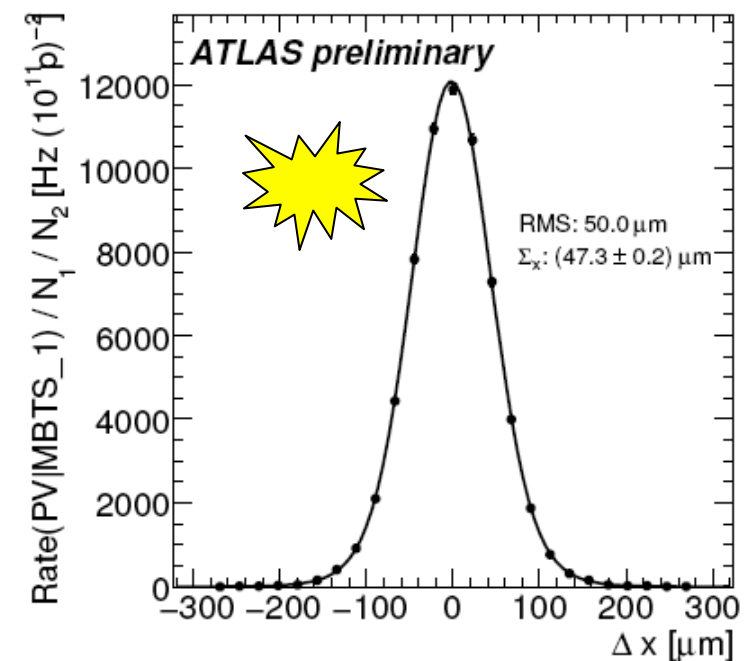


# Luminosity

$$\mathcal{L} = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$



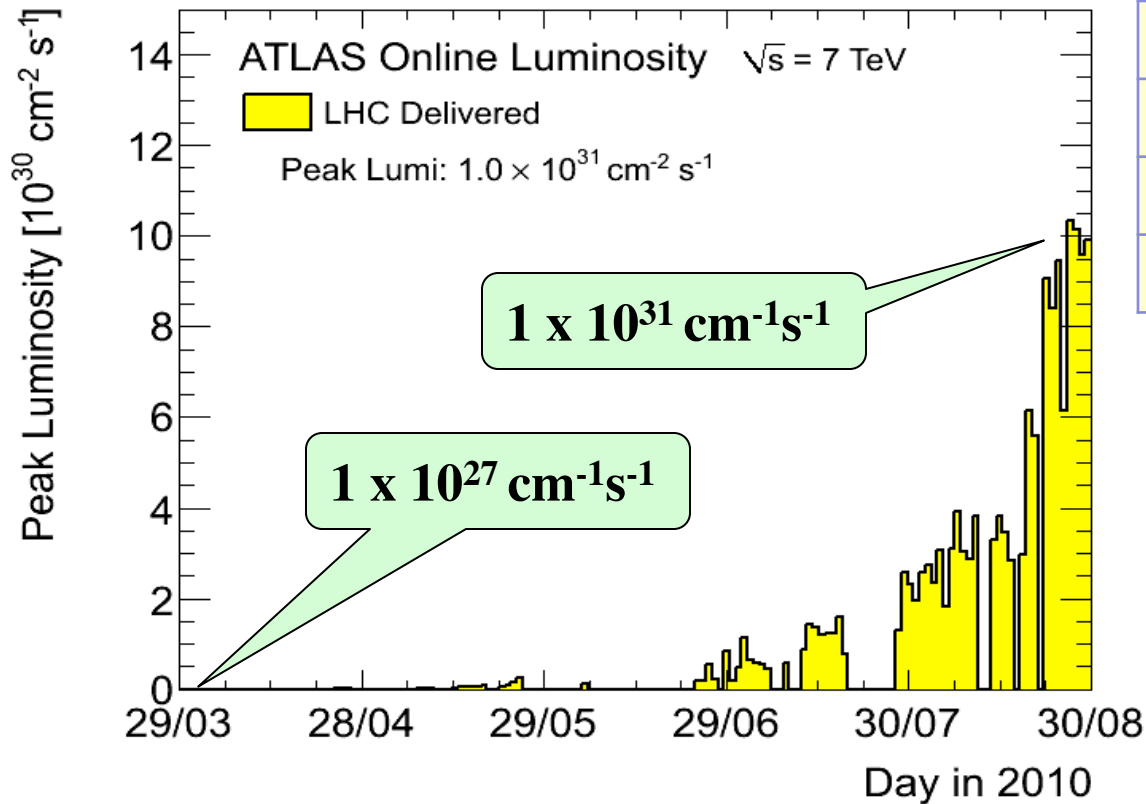
Transverse beam profile as measured in Van-der-Meer scan



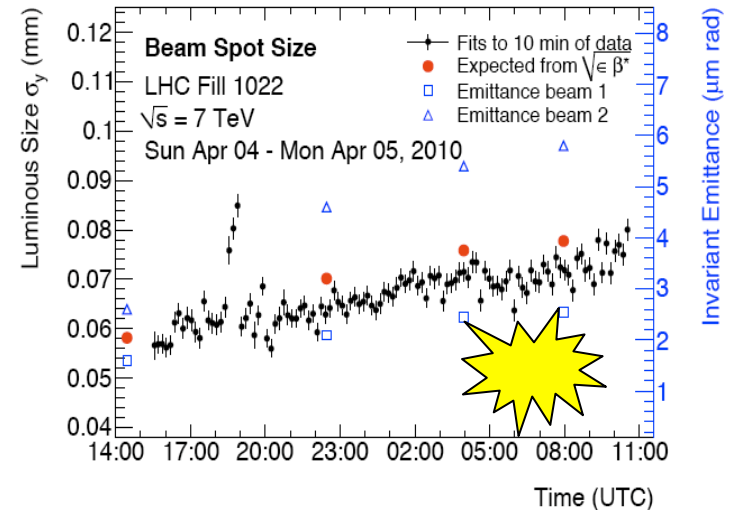
- **Delivered  $\int \mathcal{L} dt = 3.6 \text{ pb}^{-1}$** 
  - calibrated using a Van-der-Meer scan to 11% precision
    - Dominated by 10% uncertainty on beam current normalization
- **ATLAS recorded 93.9% of the data on tape**

# Peak Luminosity Evolution

$$\mathcal{L} = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$



Protons/bunch $I_1 \approx I_2$	$10^{11}$
# of bunches $n_b$	up to 36
beam size $\Sigma_x \approx \Sigma_y$	$60 \mu\text{m}$
Revolution frequency $f_r$	11 kHz



- LHC achieved 10,000 fold increase in past 6 months
  - increase in bunch current (factor  $10^2$ ) and number of bunches (factor 36) and decrease in beam size (factor 3)
- Aim at increase by another factor of 10 by end of Oct.
  - $L = 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  equivalent to  $\sim 10 \text{ pb}^{-1}$  in 24h

# ATLAS Detector Operation

- **Operational Fraction:**
  - 97-100% of subdetector channels fully operational
- **Data Quality:**
  - 94-100% of data good for physics analyses

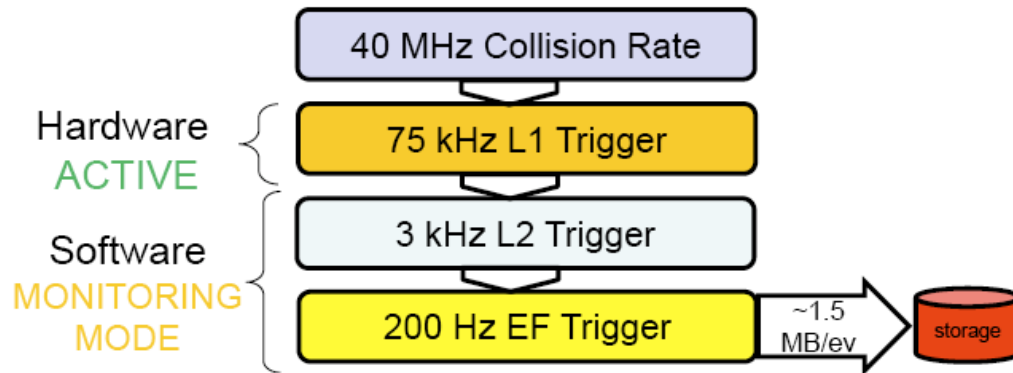


Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

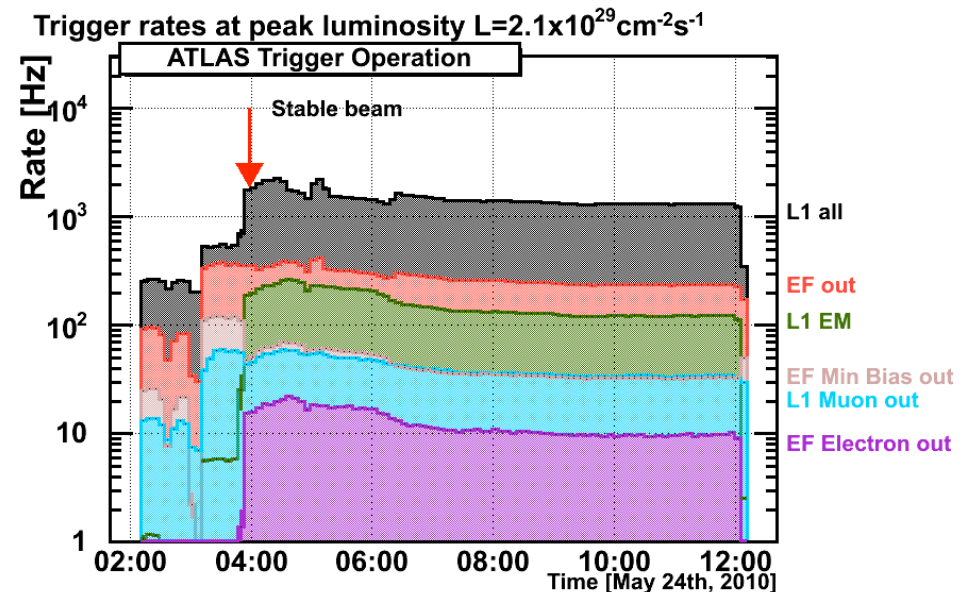
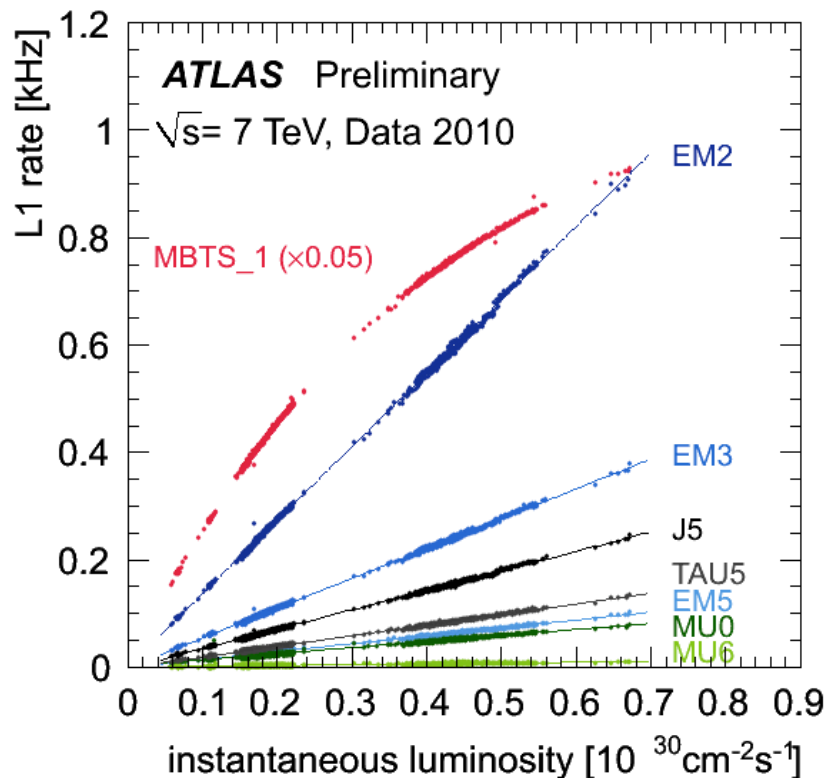
Fraction of recorded data with subdetector *good*

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
97.7	96.4	100	94.4	98.7	99.3	99.2	98.5	98.3	98.6	98.3
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams at $\sqrt{s}=7$ TeV between March 30 <sup>th</sup> and August 14 <sup>th</sup> (in %)										

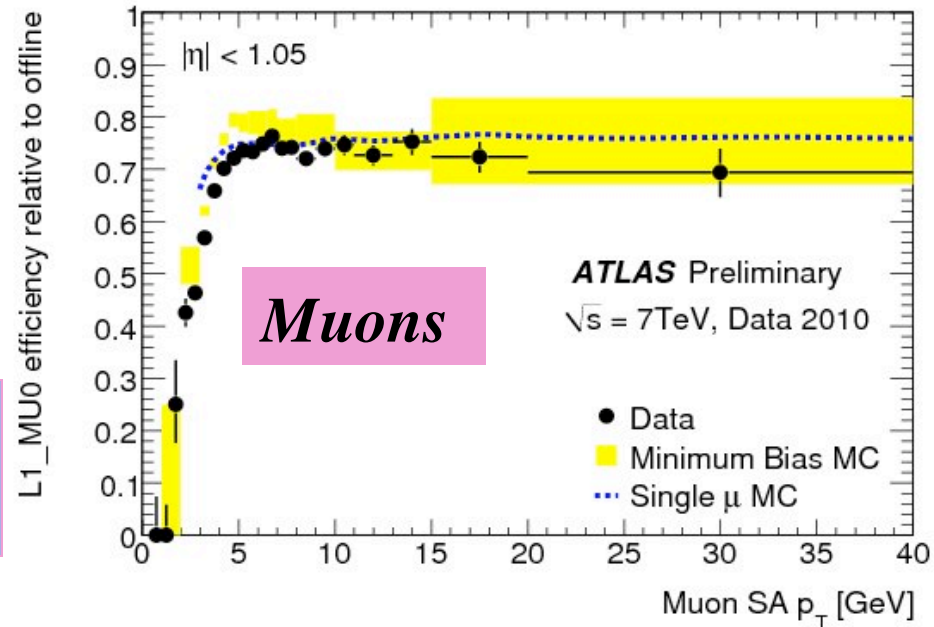
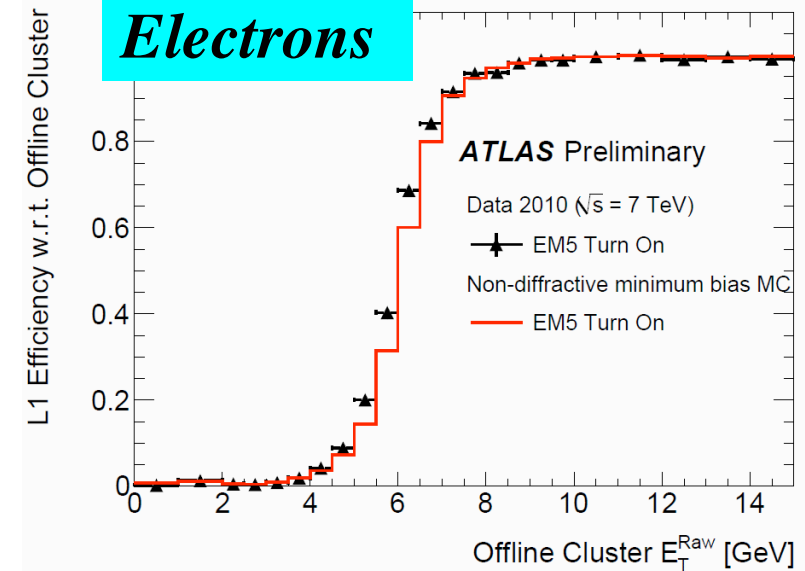
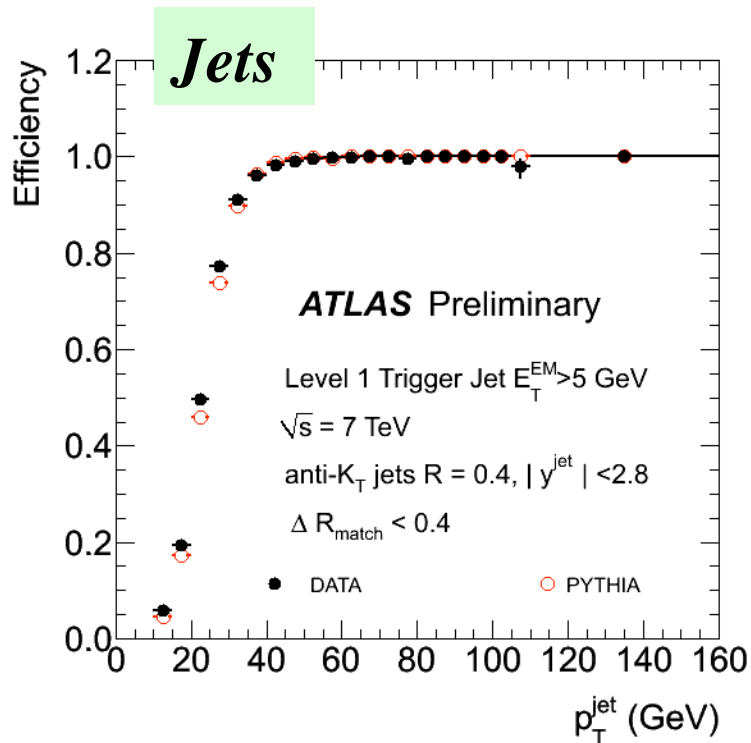
# Trigger and DAQ



- Collision rate:
  - 1<sup>st</sup> 2010 run: 50 Hz
  - Recent runs: 200 kHz
- Trigger rate today:
  - L1 ~10 kHz
  - To tape: ~300 Hz



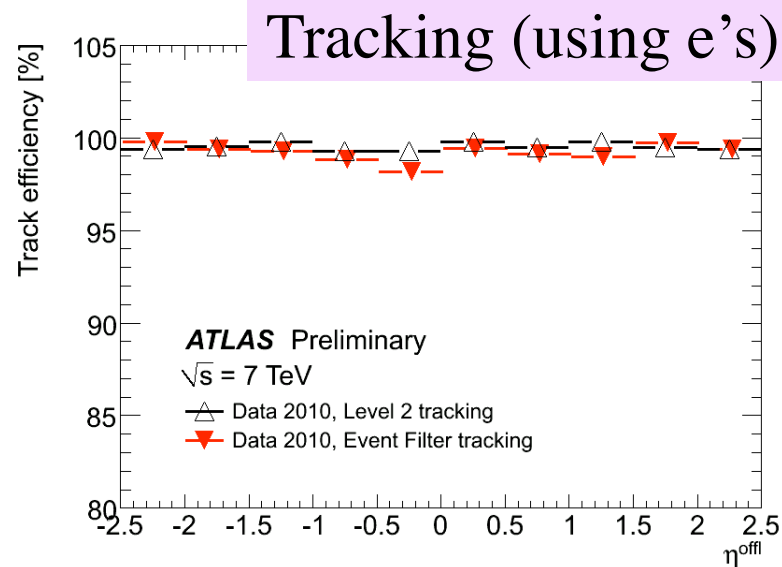
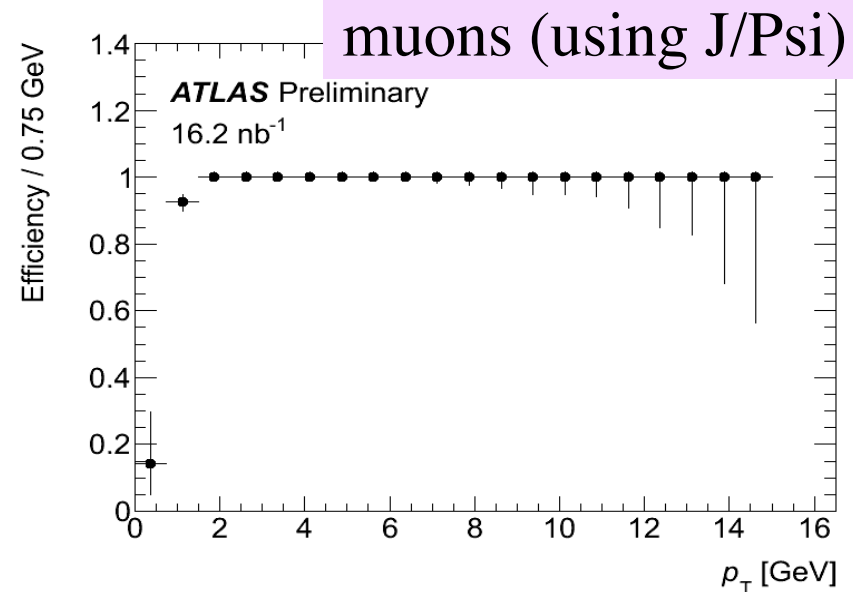
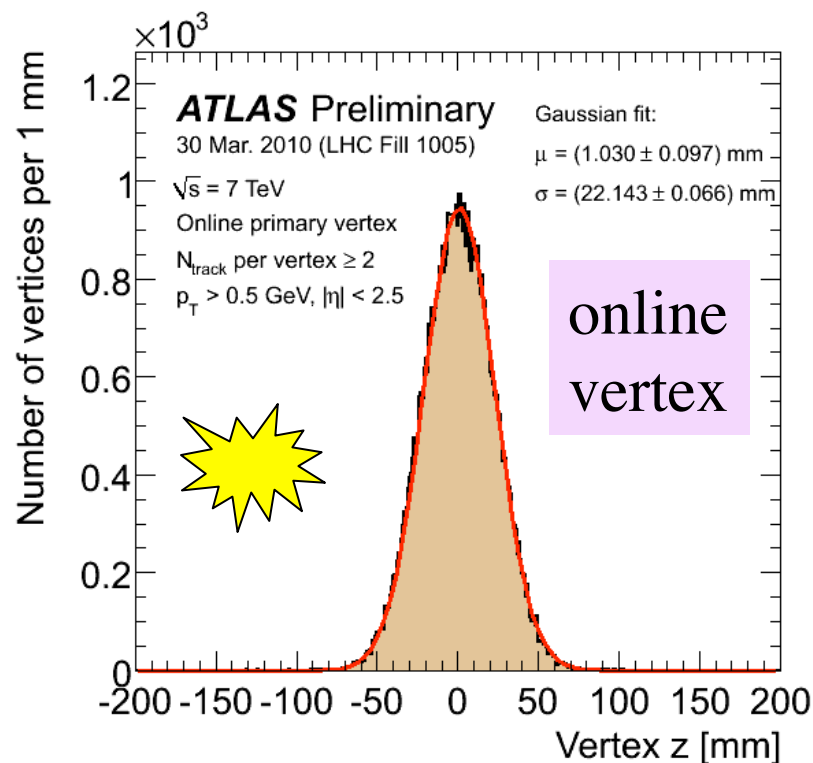
# L1 Trigger



L1 Trigger well understood,  
agrees also with simulation

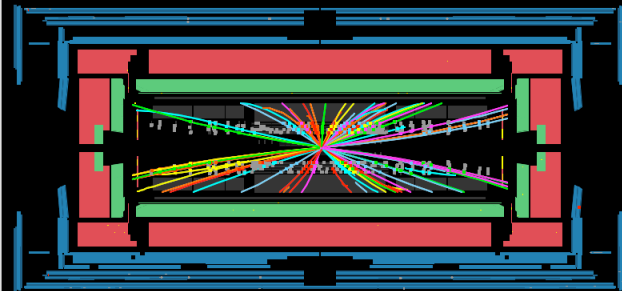
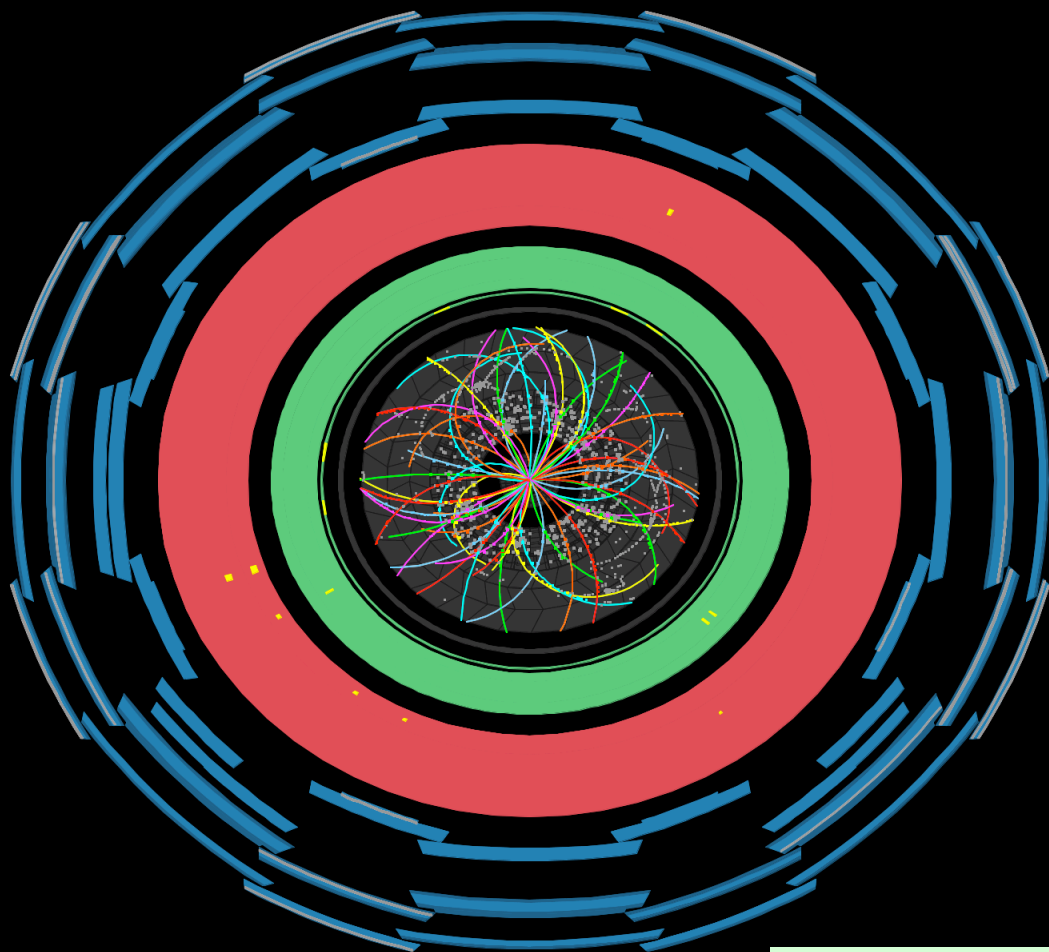
# High-Level Trigger

- High-level trigger commissioned
- Used also for online beamspot measurement
  - Important e.g. for b-jet trigger



# Minimum Bias Physics

<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>



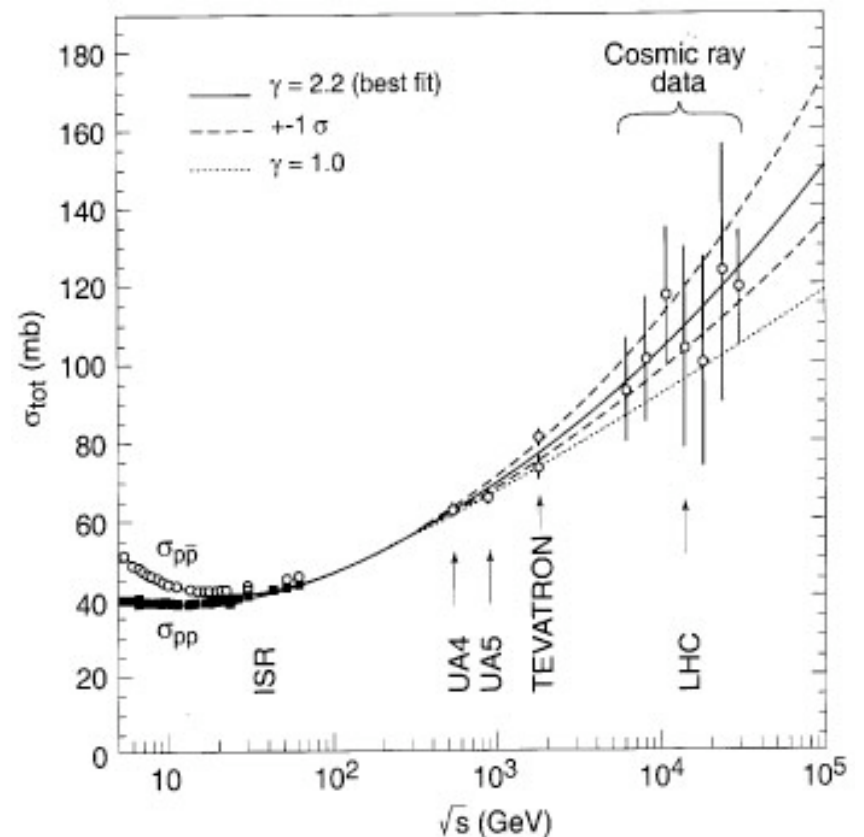
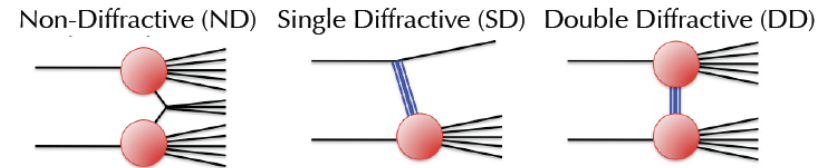
Run Number: 152166, Event Number: 316199

Date: 2010-03-30 12:58:23 CEST

one of the first 7 TeV collision  
events recorded on March 30th

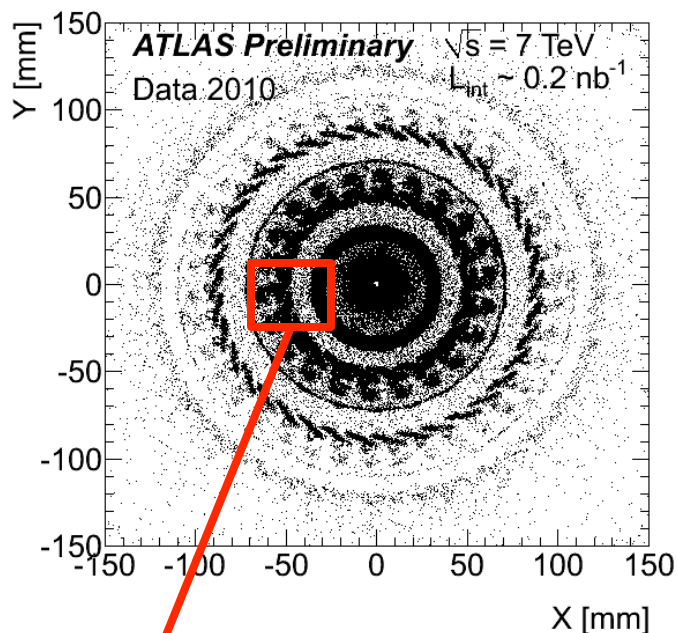
# Minimum Bias Physics

- Total cross section  $\sim 100$  mb
  - About 70% inelastic
- Measurements of charged particle multiplicities in
  - Inclusive selection
  - Diffraction enhanced selection
  - Underlying event dominated regions
- Rely on understanding of low  $p_T$  tracking of charged hadrons
  - Also important for b-tagging



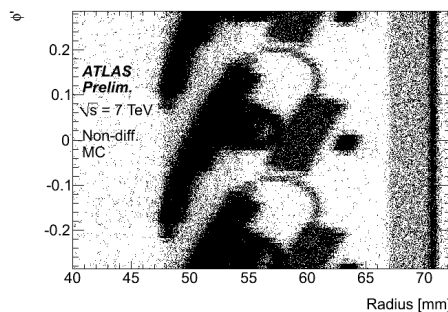
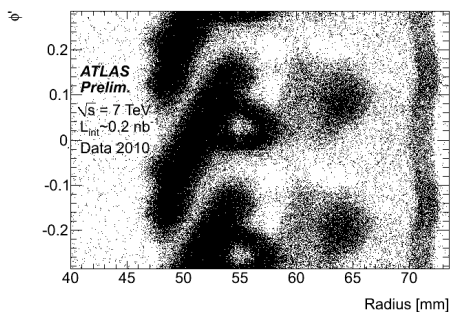
# Inner Detector: Material

Map material using hadronic interactions

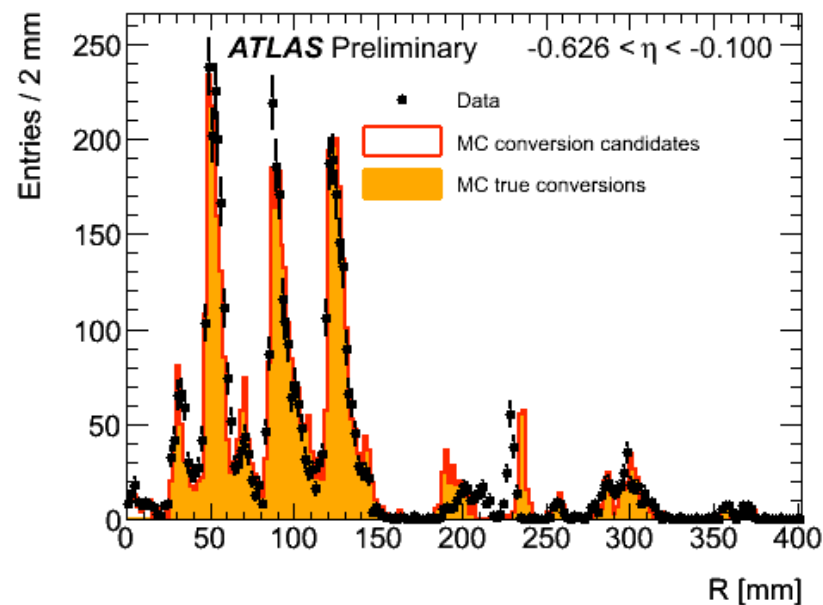



*Data*

*Simulation*



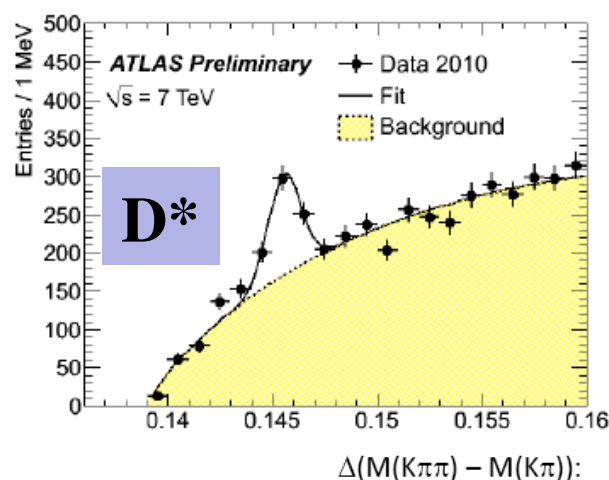
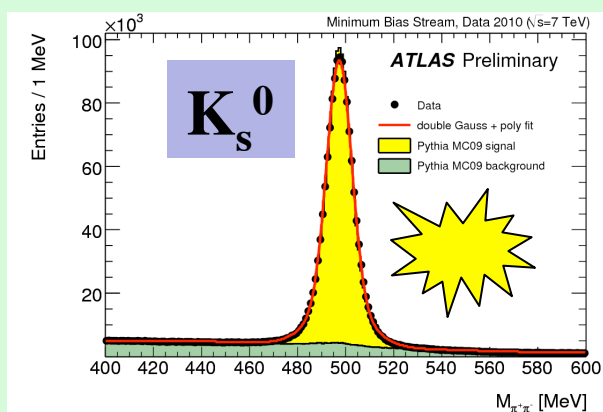
Map material with photon conversions



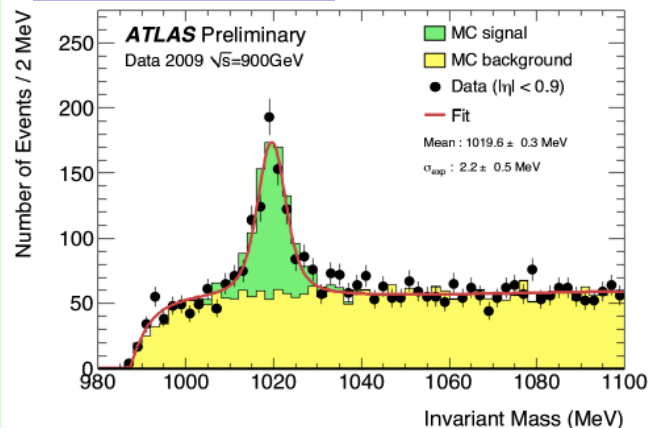
- Excellent agreement  between data and simulation
  - Small discrepancies already fixed for new MC production starting now

# Inner Detector: Resolution, Scale and particle ID

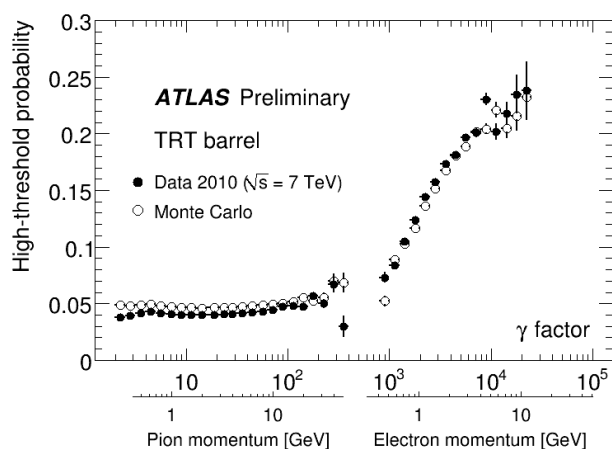
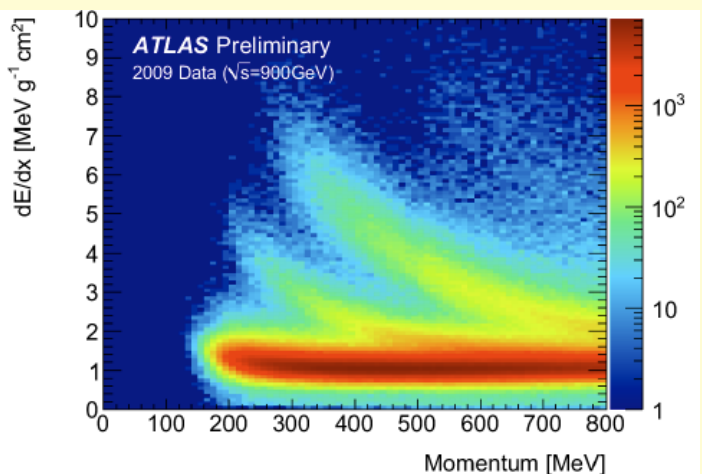
## Resolution and Mass Scale using resonances



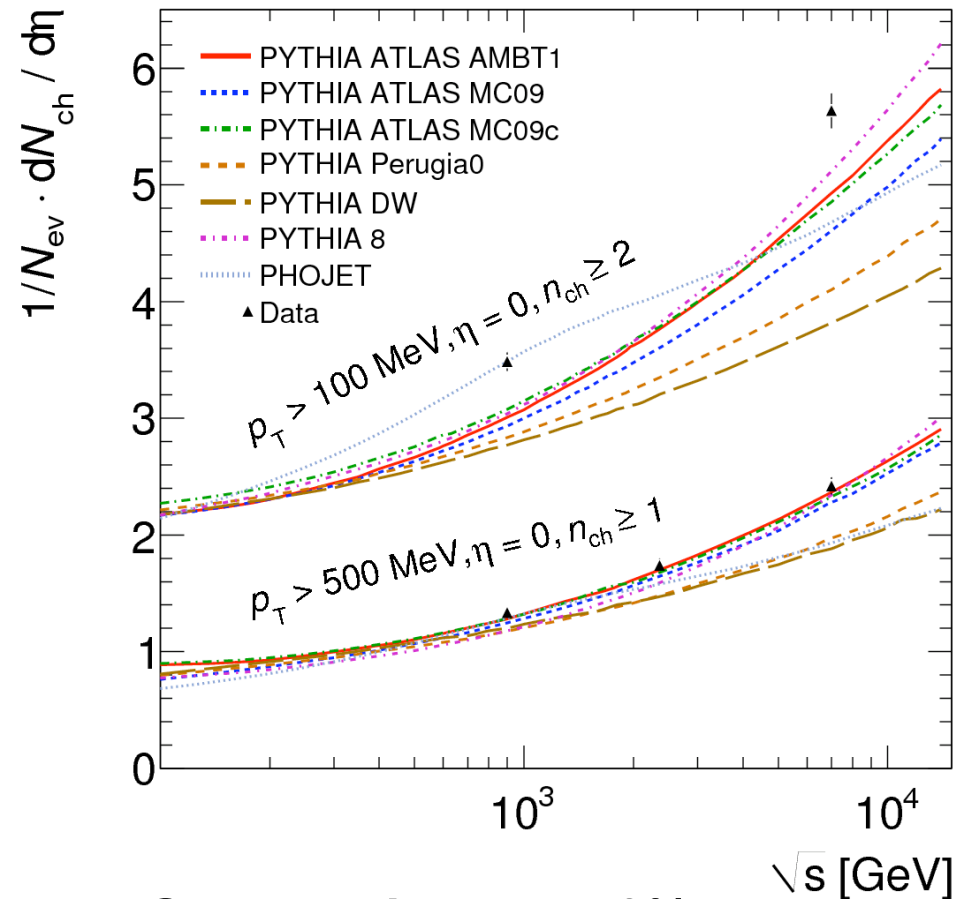
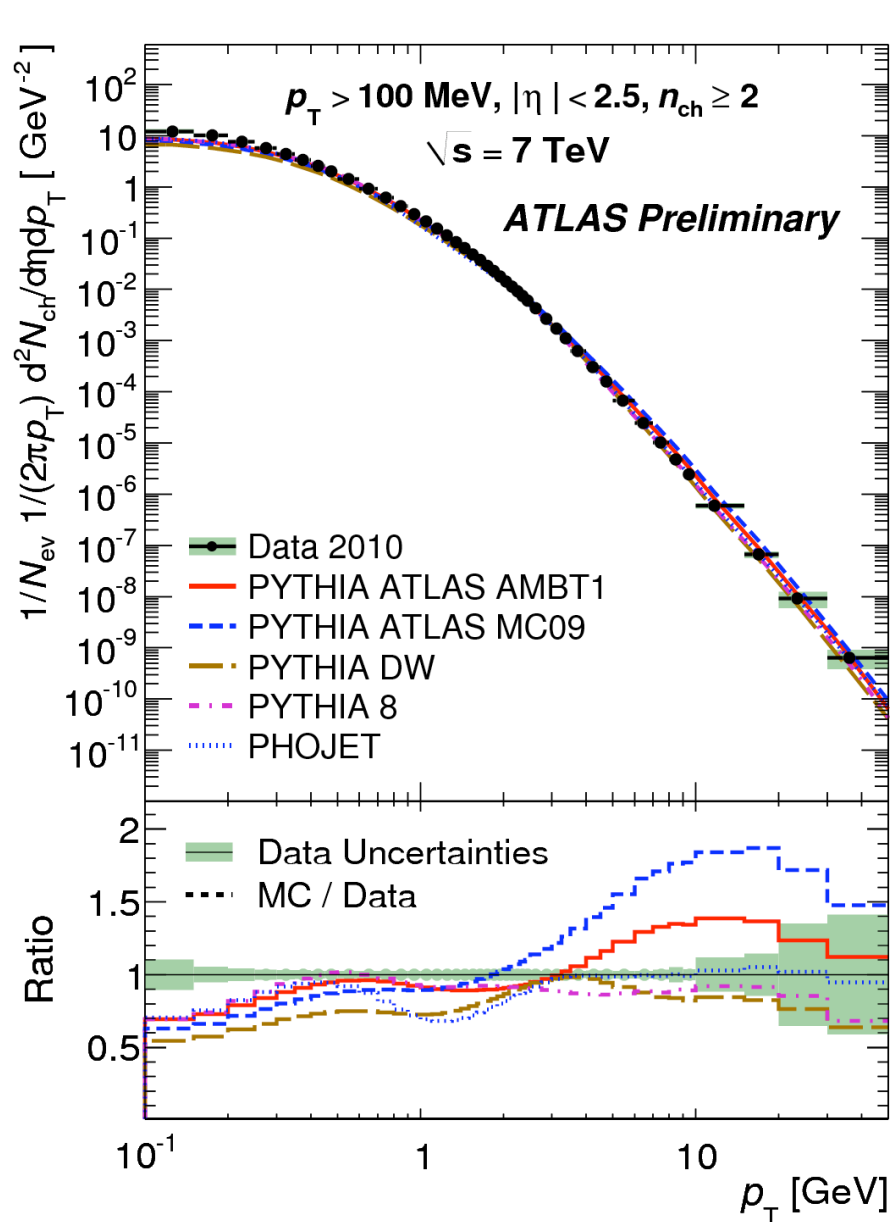
$\Phi \rightarrow K^+ K^-$



## Particle identification using Pixel dE/dx and TRT transition radiation



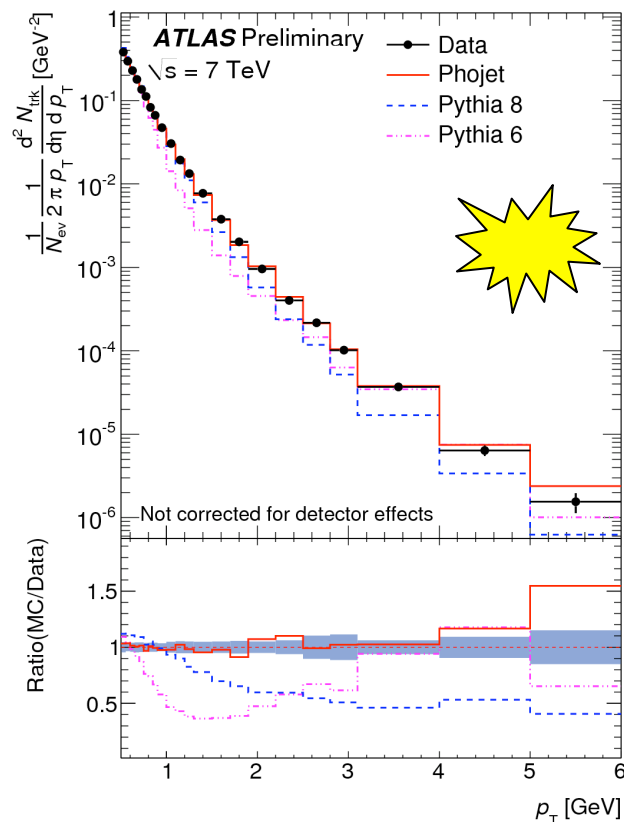
# Inclusive Charged Particle Spectra



- **Systematic error ~3%**
- **MC models agree to within 50%**
  - But require further tuning
- **Multiplicity rises with energy**

# Charged Particles in diffractive events, the Underlying Event and Jets

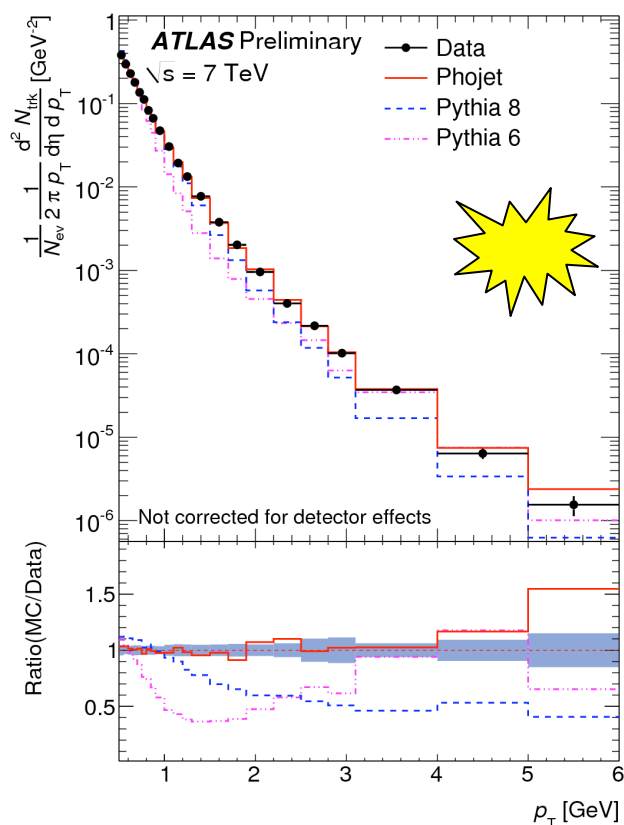
Charged particle spectra in diffractive-enhanced sample: veto events with hits on both sides of MBTS detector



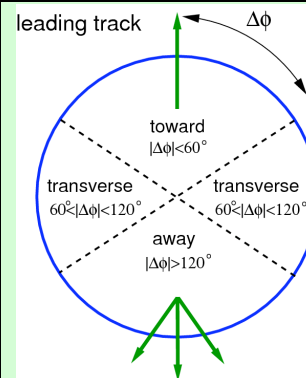
*Phojet describes data best*

# Charged Particles in diffractive events, the Underlying Event and Jets

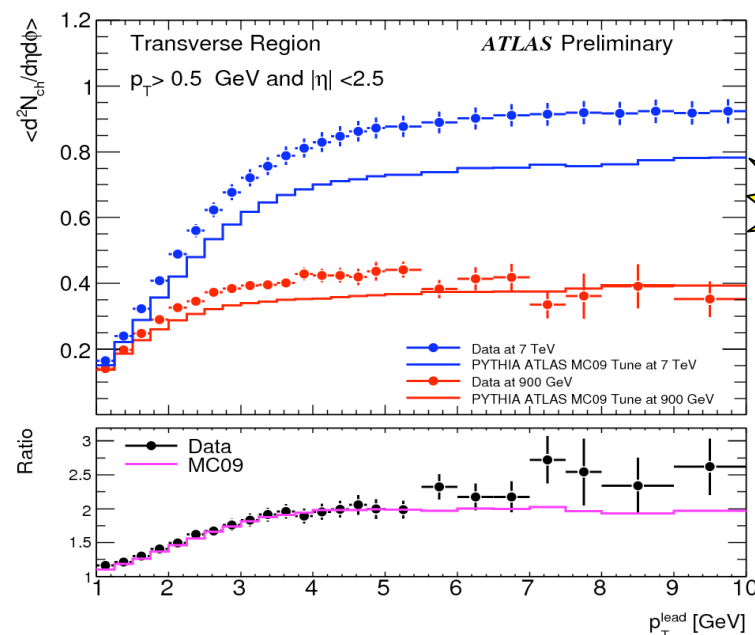
Charged particle spectra in diffractive-enhanced sample: veto events with hits on both sides of MBTS detector



*Phojet describes data best*



Transverse region w.r.t. leading track: sensitive to *initial-state radiation* and *multiple parton-parton interactions*

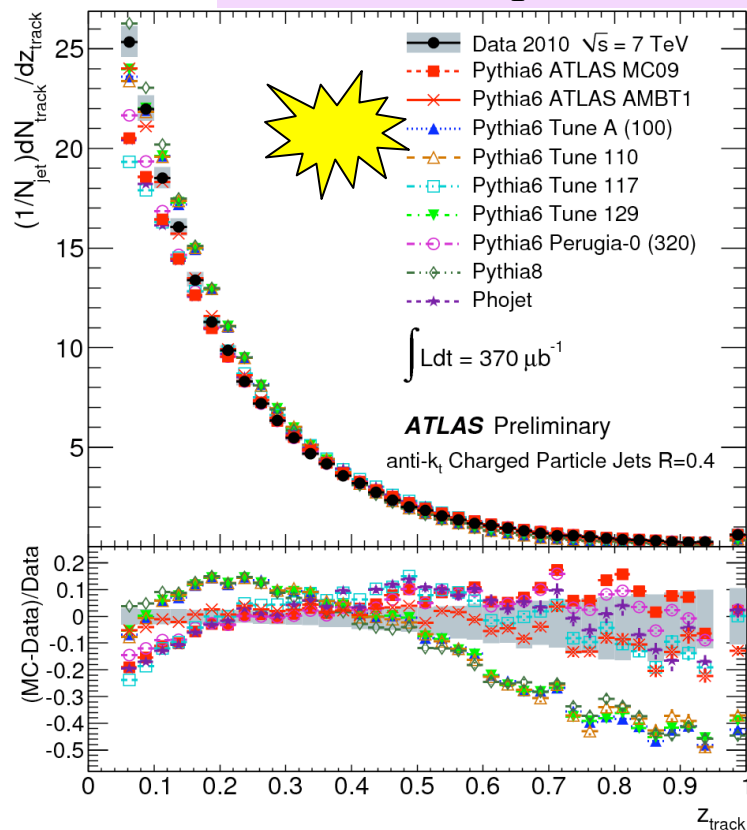


*Pythia tunes underestimate both at 0.9 and 7 TeV*

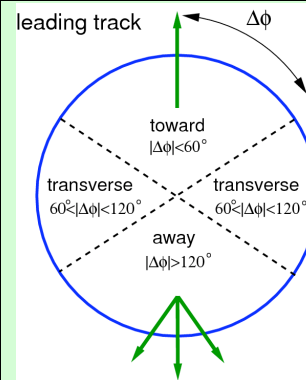
# Charged Particles in diffractive events, the Underlying Event and Jets

Use tracks to form jets => test fragmentation of jets

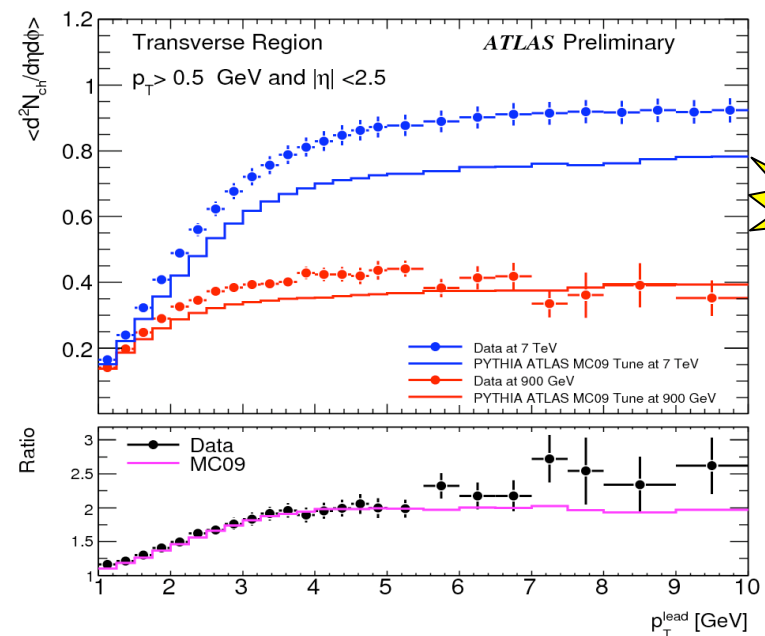
$$10 \text{ GeV} < p_T^{\text{jet}} < 15 \text{ GeV}$$



MC tunes have varying success in describing the fragmentation

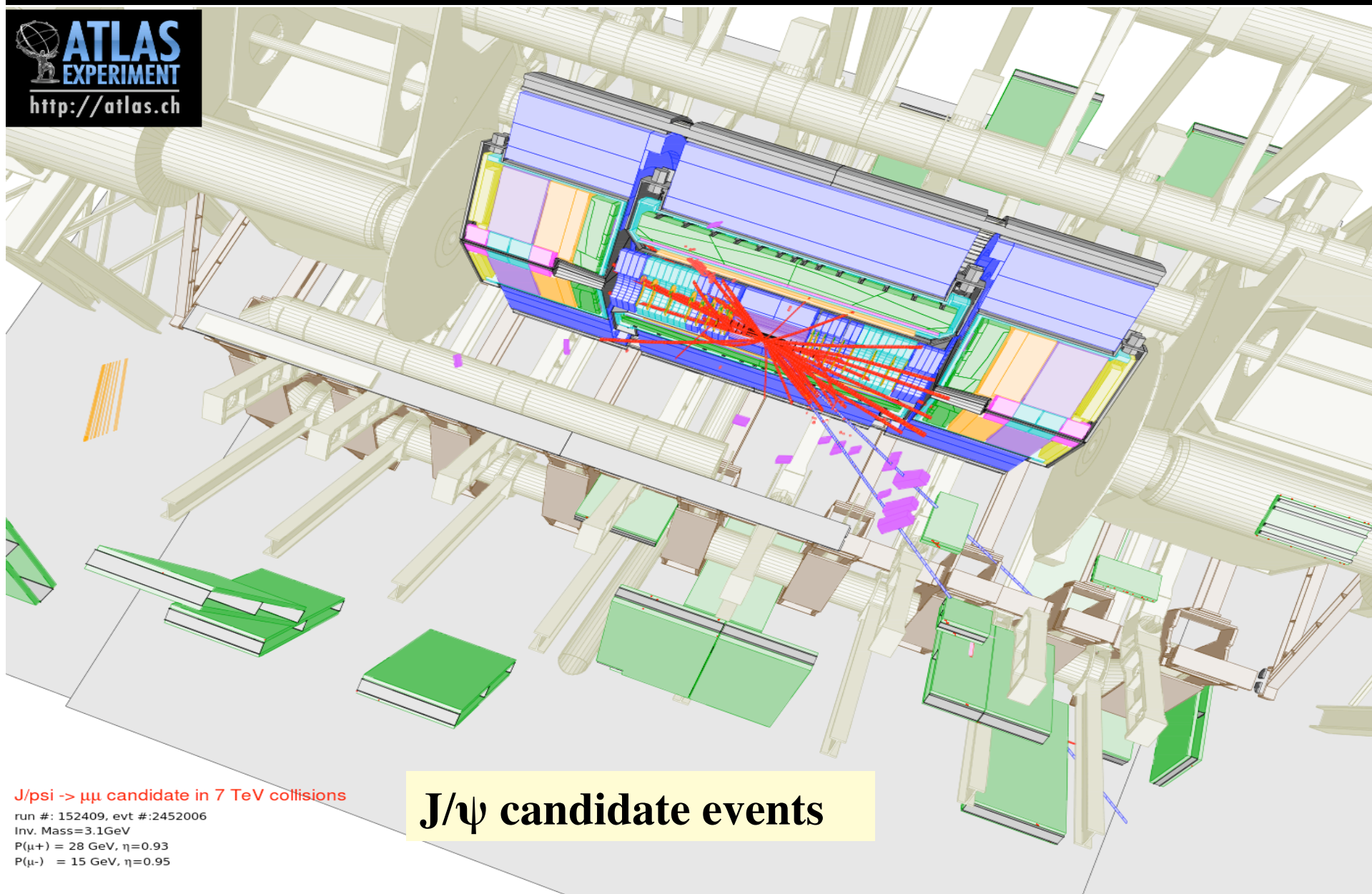


Transverse region w.r.t. leading track: sensitive to *initial-state radiation* and *multiple parton-parton interactions*



Pythia tune underestimates both at 0.9 and 7 TeV

# $J/\psi$ and $\Upsilon$



$J/\psi \rightarrow \mu\mu$  candidate in 7 TeV collisions

run #: 152409, evt #: 2452006

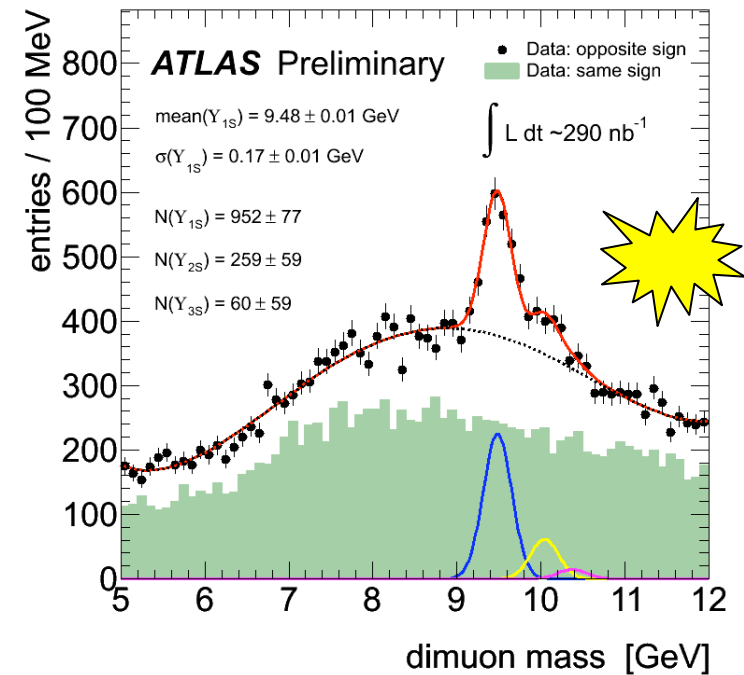
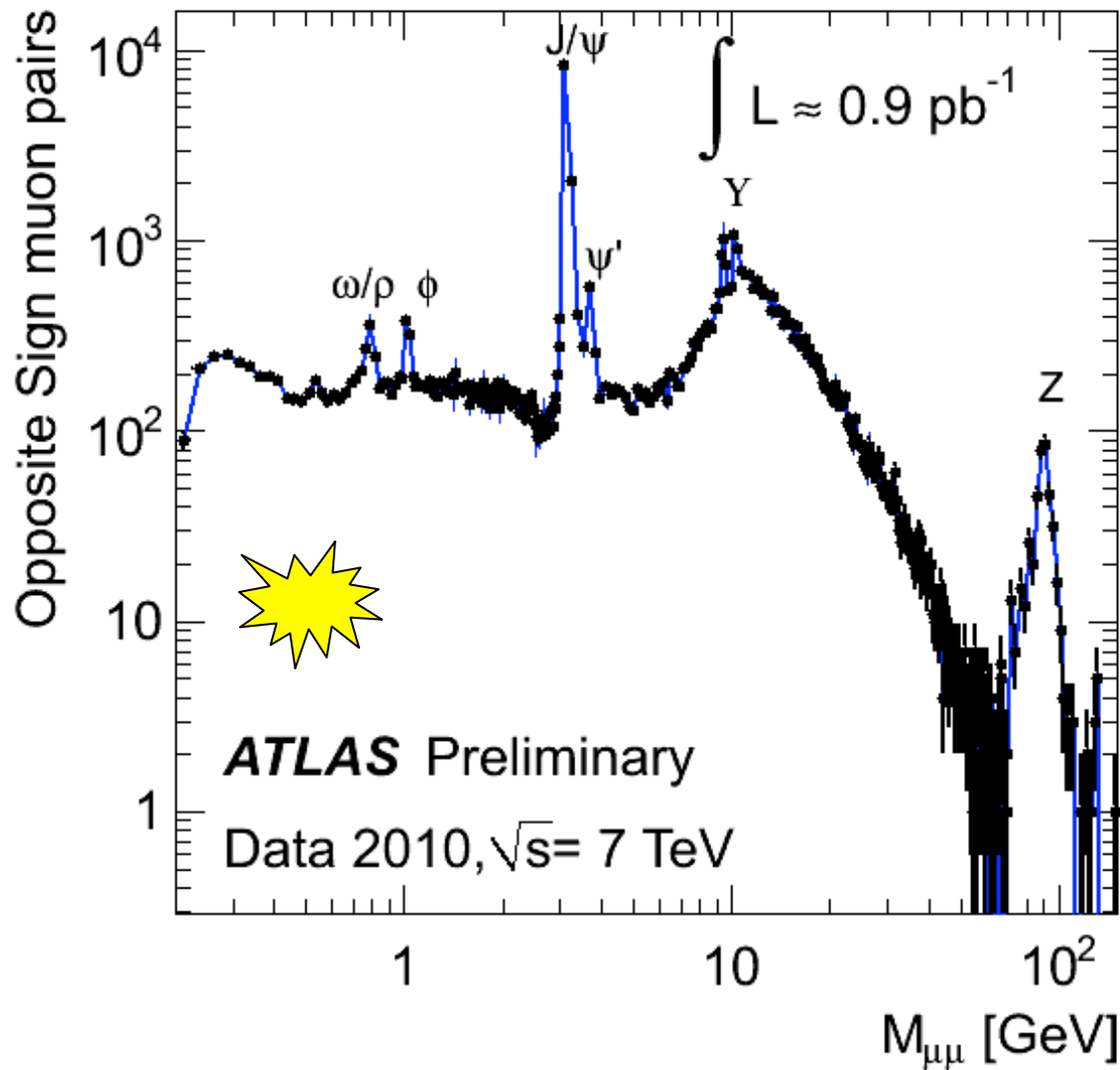
Inv. Mass = 3.1 GeV

$P(\mu^+) = 28 \text{ GeV}$ ,  $\eta = 0.93$

$P(\mu^-) = 15 \text{ GeV}$ ,  $\eta = 0.95$

$J/\psi$  candidate events

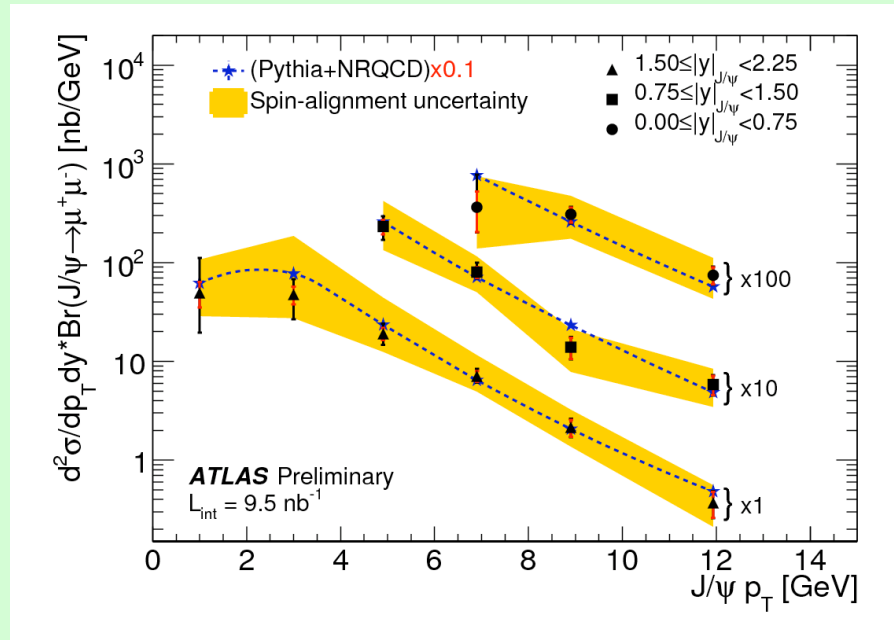
# Dimuon Mass Spectrum



Will now also constitute  
excellent calibration  
samples

# J/ψ Cross Sections

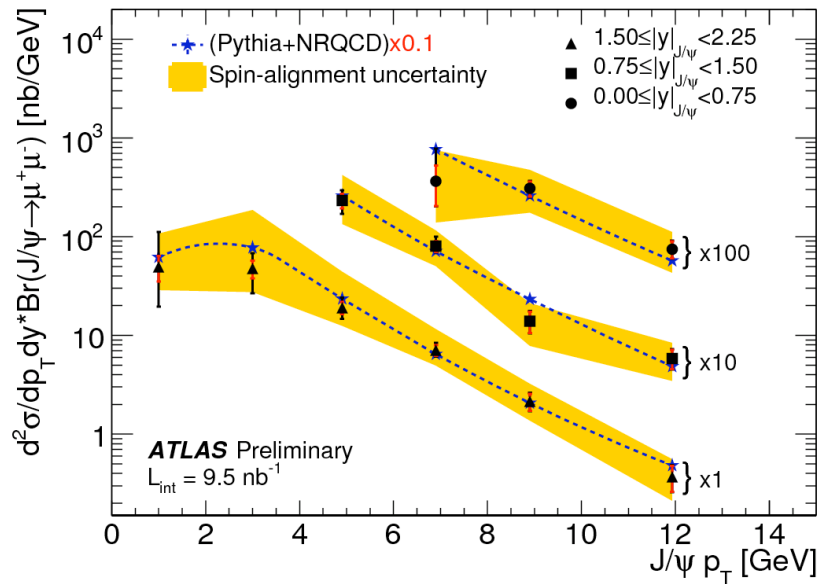
## Inclusive cross section



- Kin. range:  $p_T=1\text{-}12 \text{ GeV}$ ,  $|y|<2.25$
- Syst. Uncertainty  $\sim 30\%$ 
  - Completely dominated by polarization uncertainty
- $p_T$  and  $y$ -dependence of  $\sigma(J/\psi)$  agrees with Pythia color octet model
  - Normalization off by factor 10

# J/ψ Cross Sections

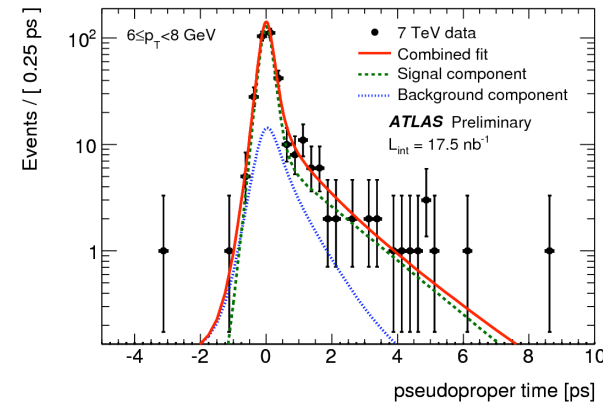
## Inclusive cross section



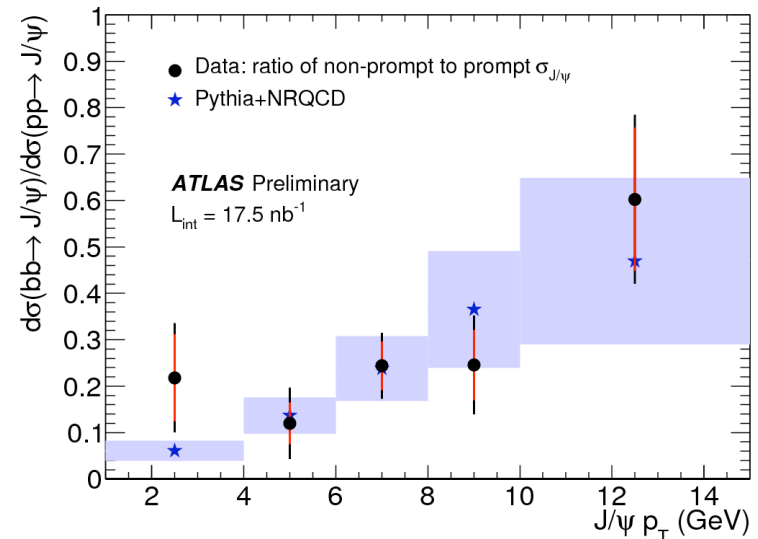
- Kin. range:  $p_T=1-12$  GeV,  $|y|<2.25$
- Syst. Uncertainty ~30%
  - Completely dominated by polarization uncertainty
- $p_T$  and  $y$ -dependence of  $\sigma(J/\psi)$  agrees with Pythia color octet model
  - Normalization off by factor 10

Prompt fraction determined  
From pseudo-proper time  
distribution

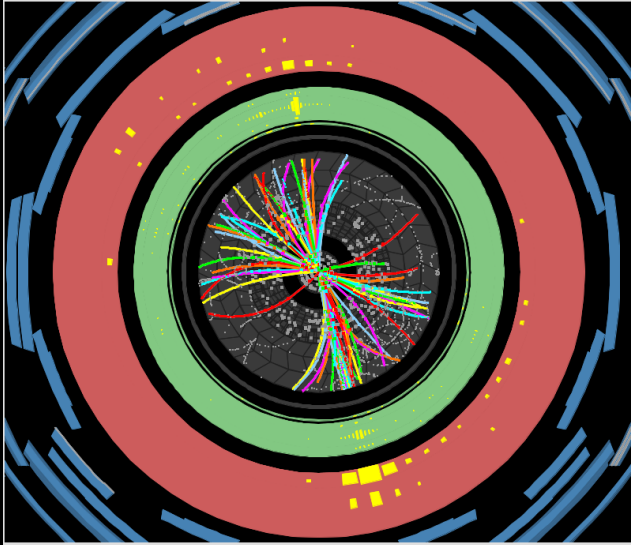
$$\tau = \frac{L_{xy} m(J/\psi)}{p_T(J/\psi)}$$



## Non-prompt fraction



# Jets

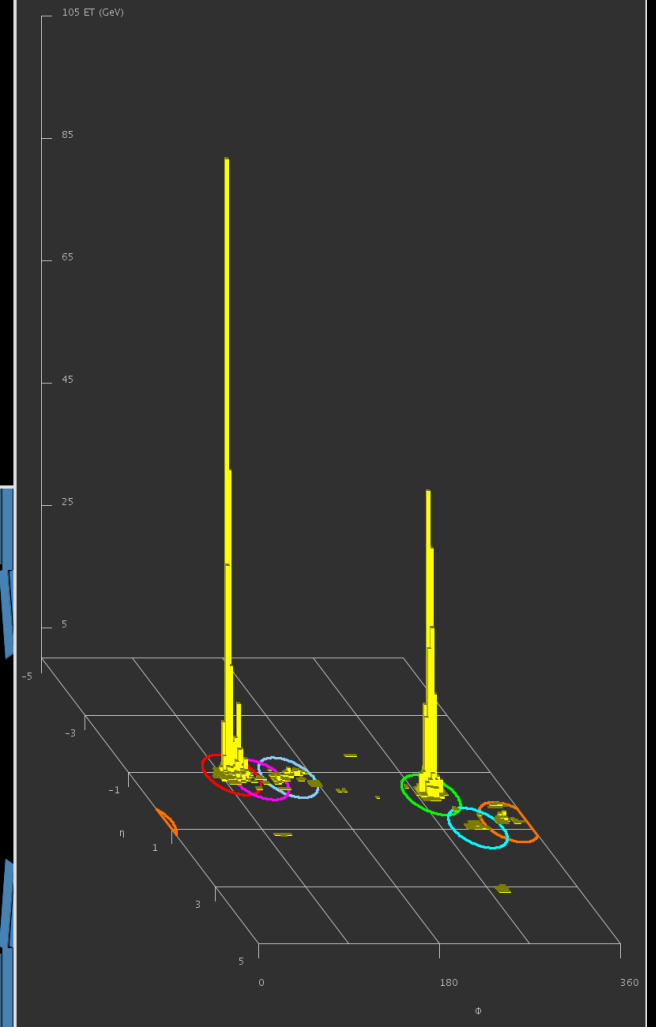
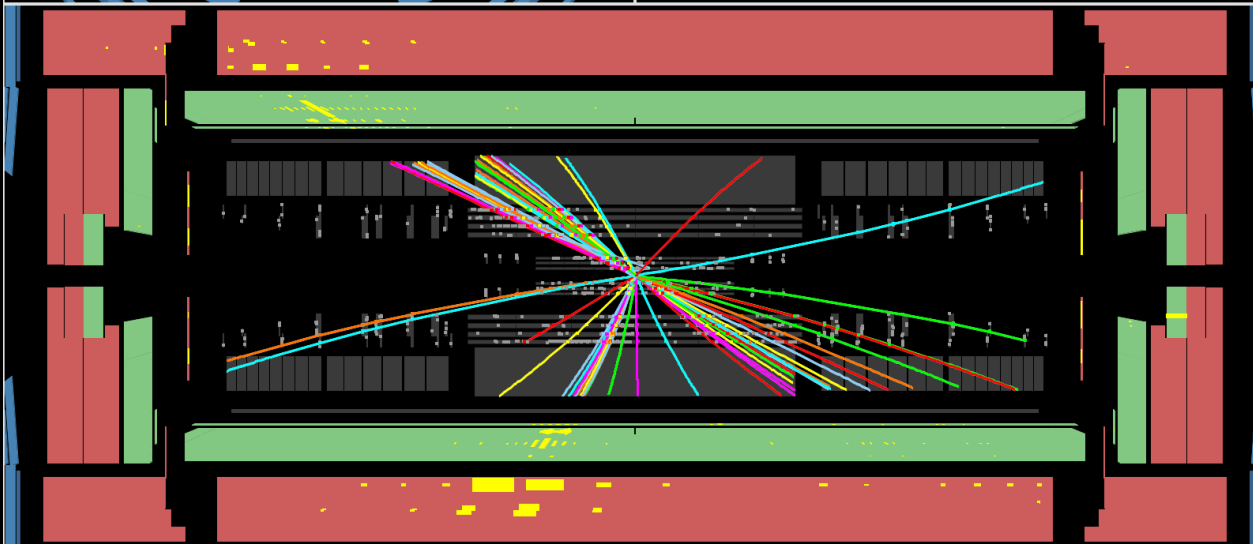


**ATLAS**  
**EXPERIMENT**

Run Number: 152166, Event Number: 810258

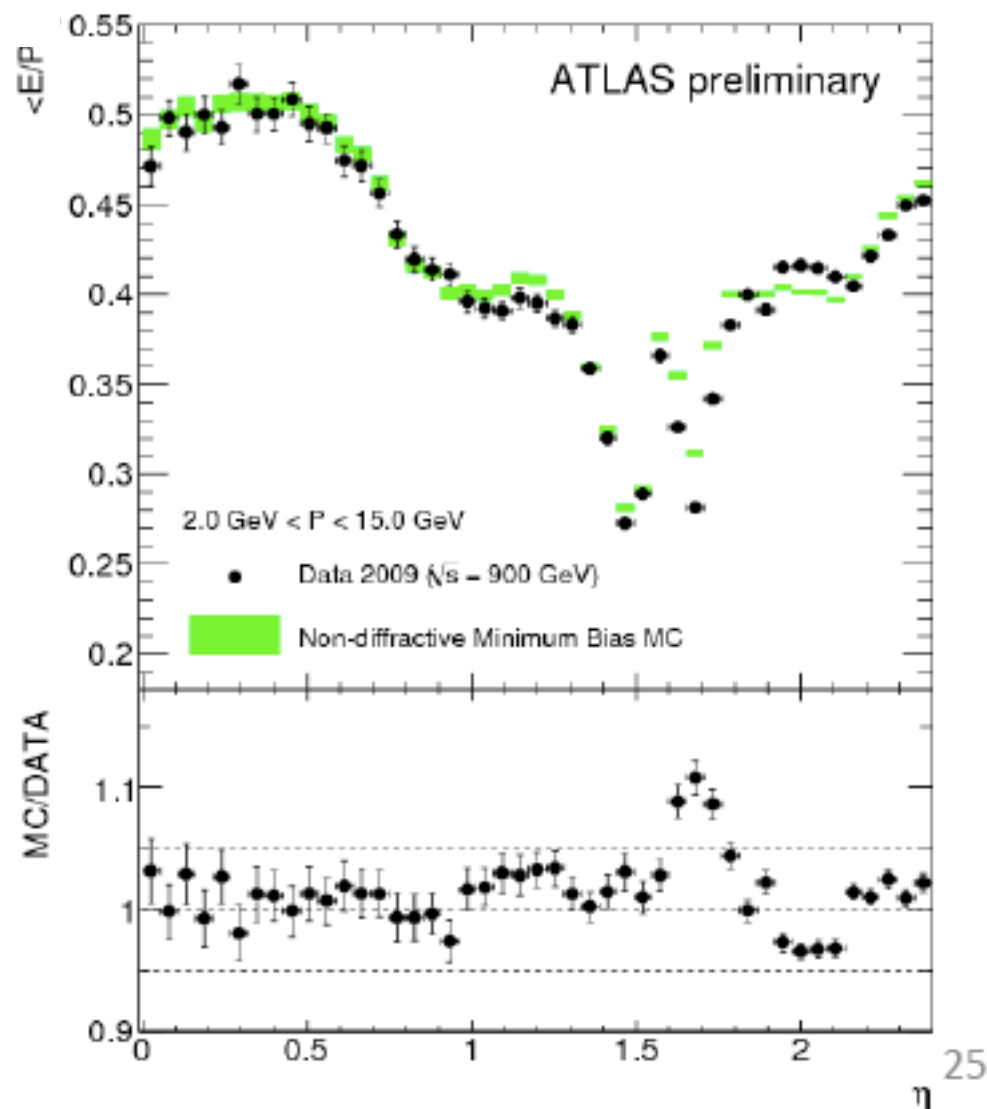
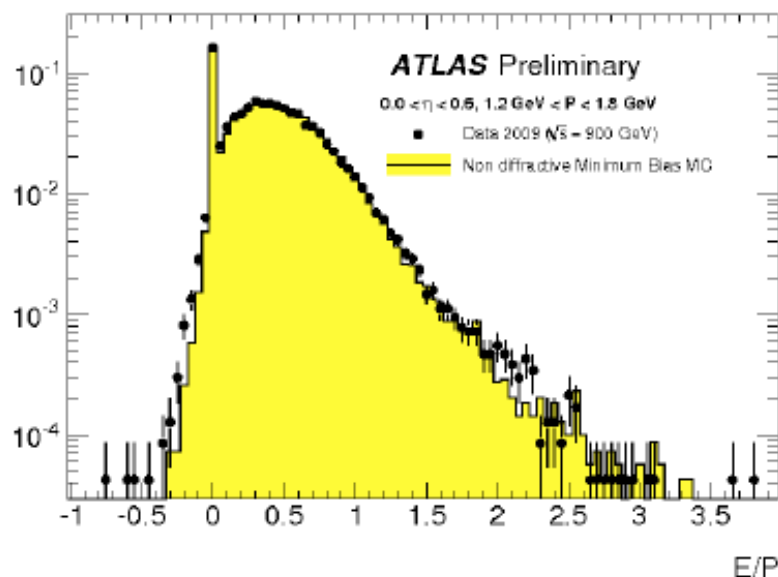
Date: 2010-03-30 14:56:29 CEST

**Di-jet Event at 7 TeV**



**Raw measured jet energy: 300 GeV**

# Calorimeter Response

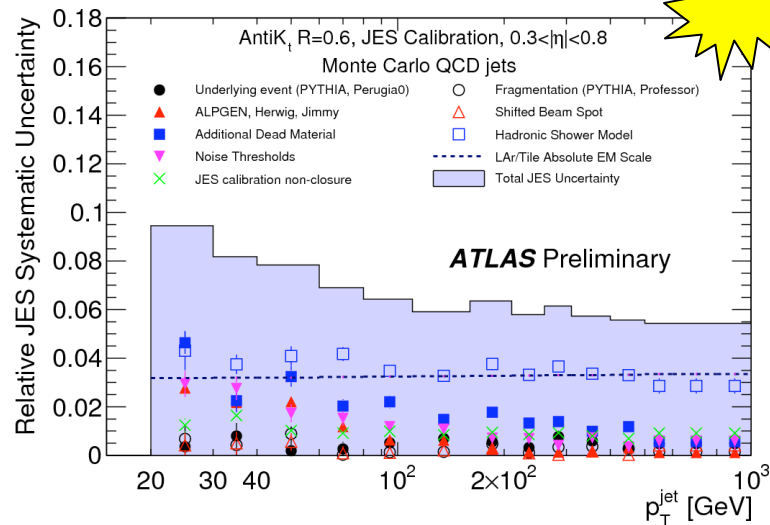


- Calorimeter energy in  $R=0.2$  cone around track / track  $p$
- Measures response of calorimeter to charged pions
  - Critical for jet calibration

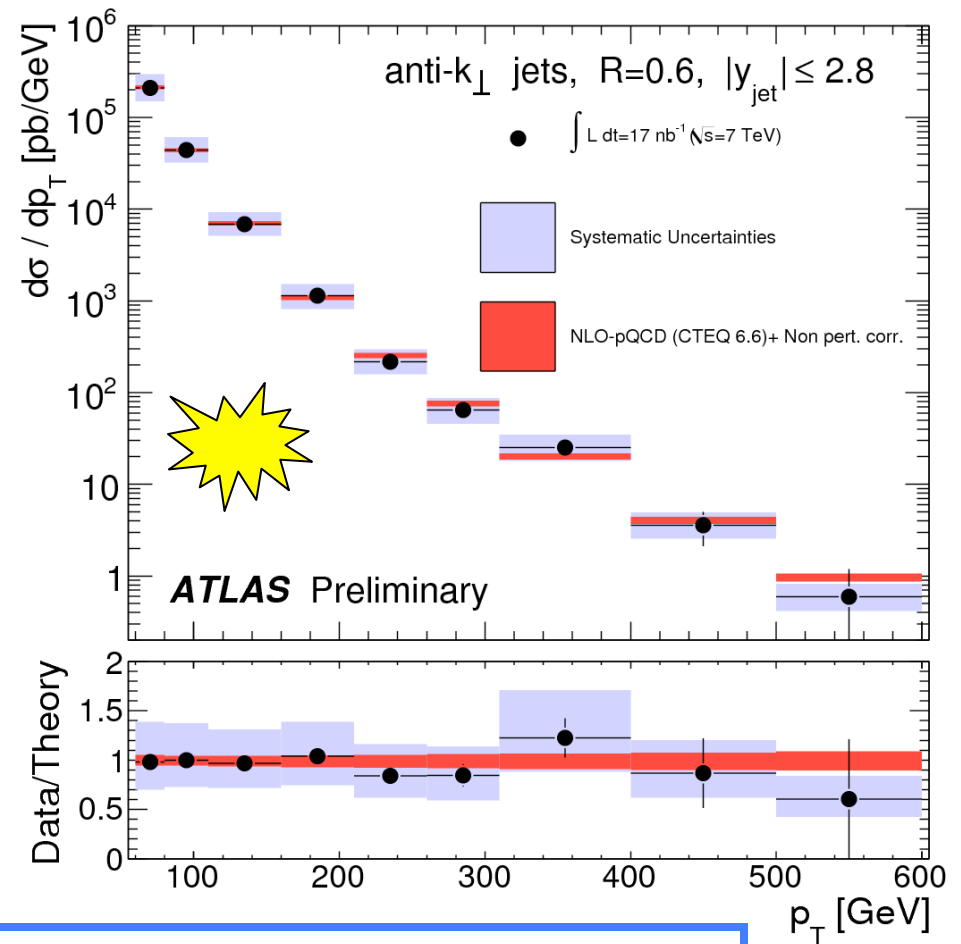
- Data generally very well described by MC

# Inclusive Jet Cross Section

Jet Energy Scale uncertainty  
6-10% depending on  $p_T$  and  $\eta$   
(dominated by EM scale and  
hadronic shower model)

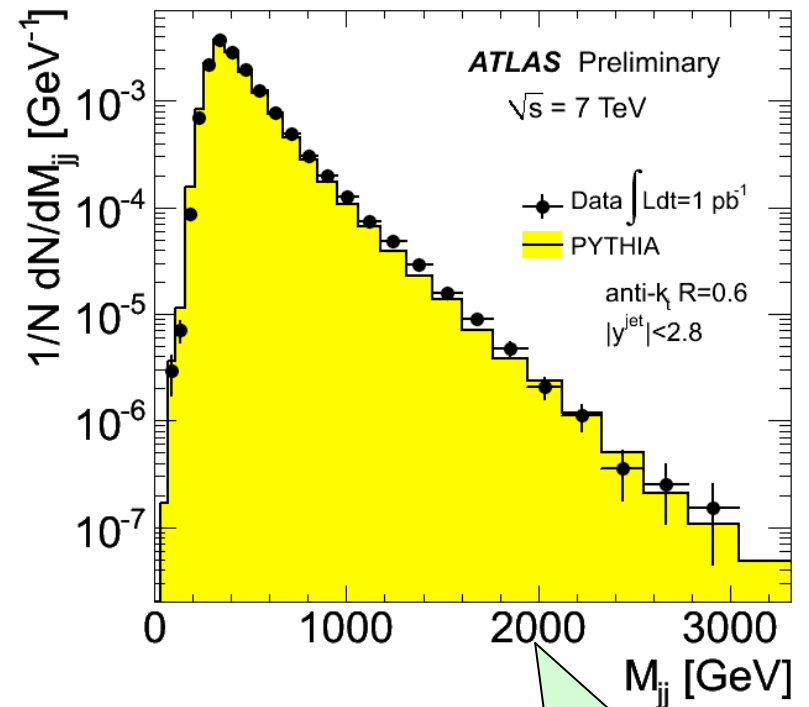
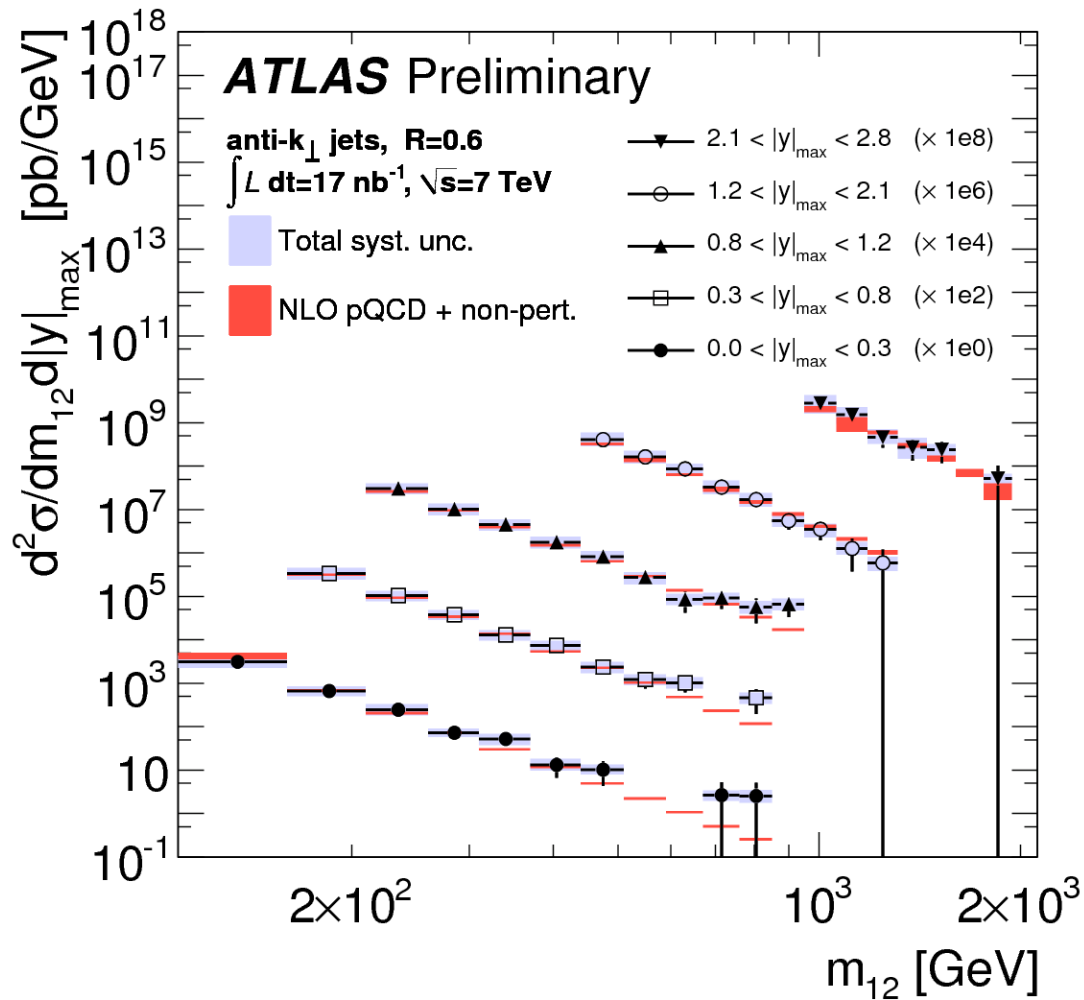


Workshop on SLAC last week



- Jet cross section measured using anti- $k_T$  algorithm
  - Up to  $p_T = 500 \text{ GeV}$  (with  $17 \text{ nb}^{-1}$ )
  - Dominant systematic uncertainty: jet energy scale
- Data in good agreement with QCD prediction

# Dijet Mass



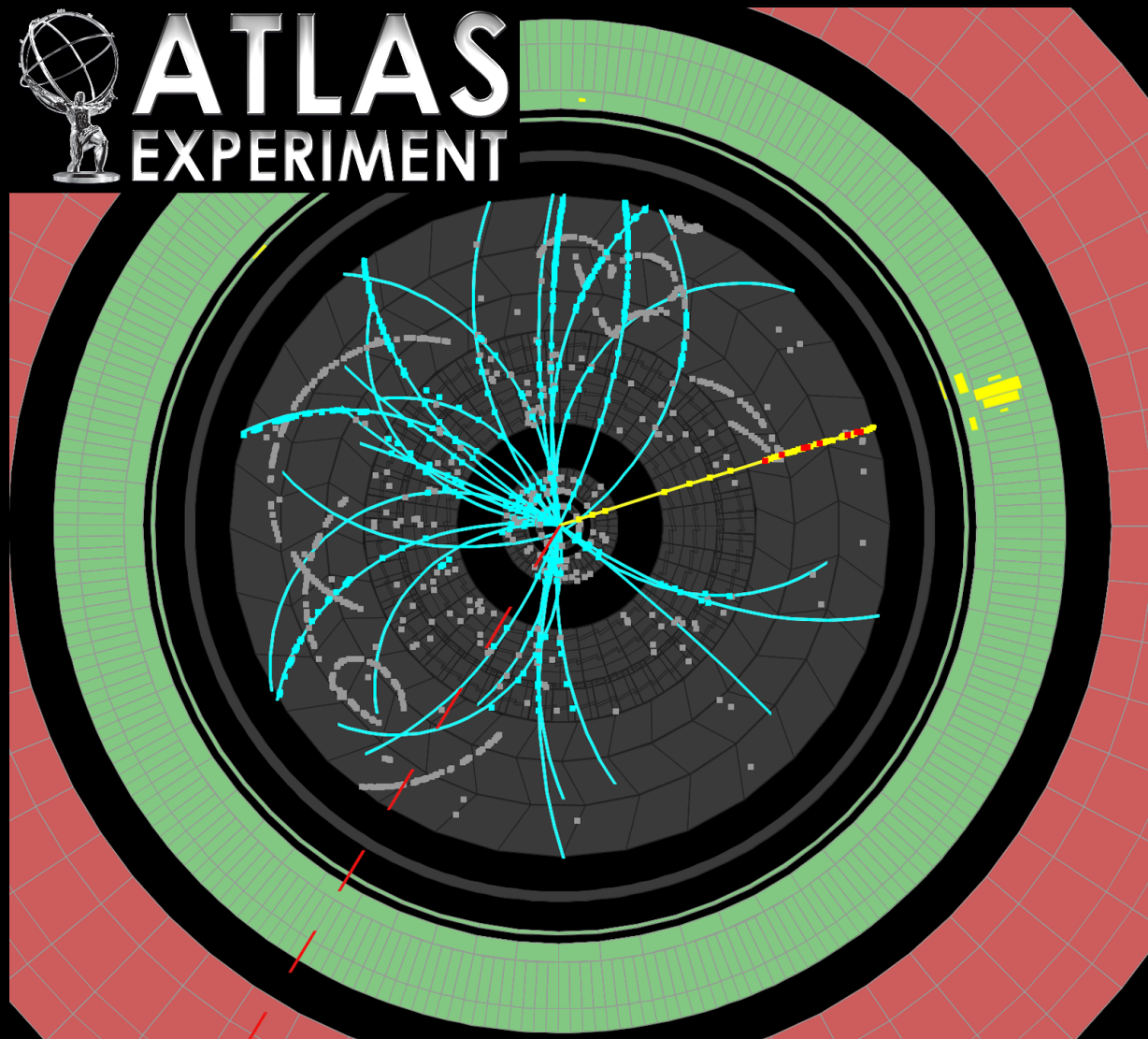
Data extend beyond  
Tevatron's  $\sqrt{s}$

- Excellent agreement of data with QCD prediction

$$W \rightarrow e \nu_e$$

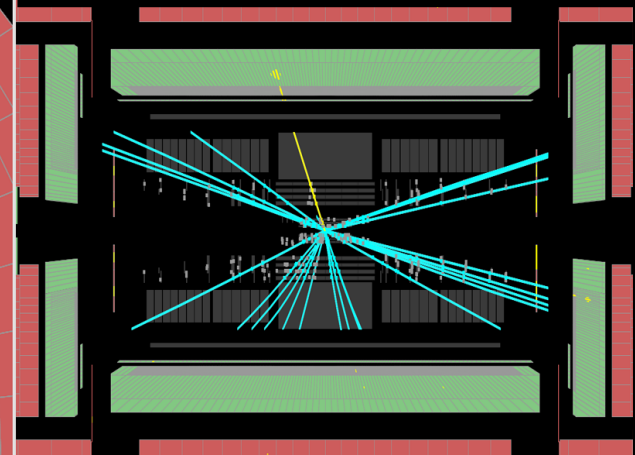


**ATLAS**  
EXPERIMENT



Run Number: 152409, Event Number: 5966801

Date: 2010-04-05 06:54:50 CEST



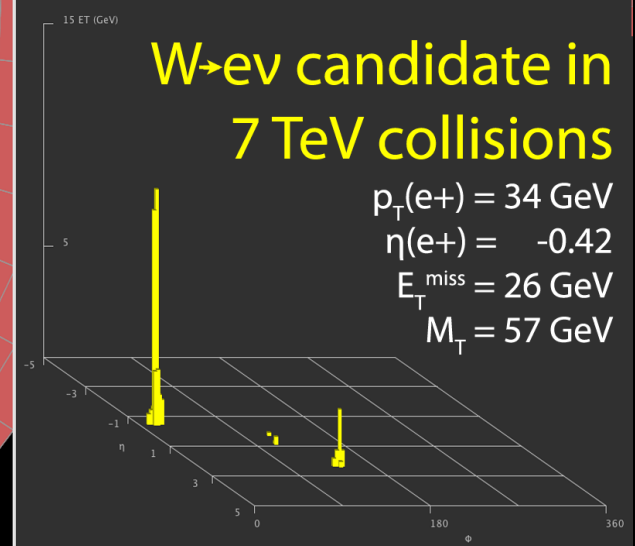
**$W \rightarrow e \nu$  candidate in  
7 TeV collisions**

$$p_T(e^+) = 34 \text{ GeV}$$

$$\eta(e^+) = -0.42$$

$$E_T^{\text{miss}} = 26 \text{ GeV}$$

$$M_T = 57 \text{ GeV}$$



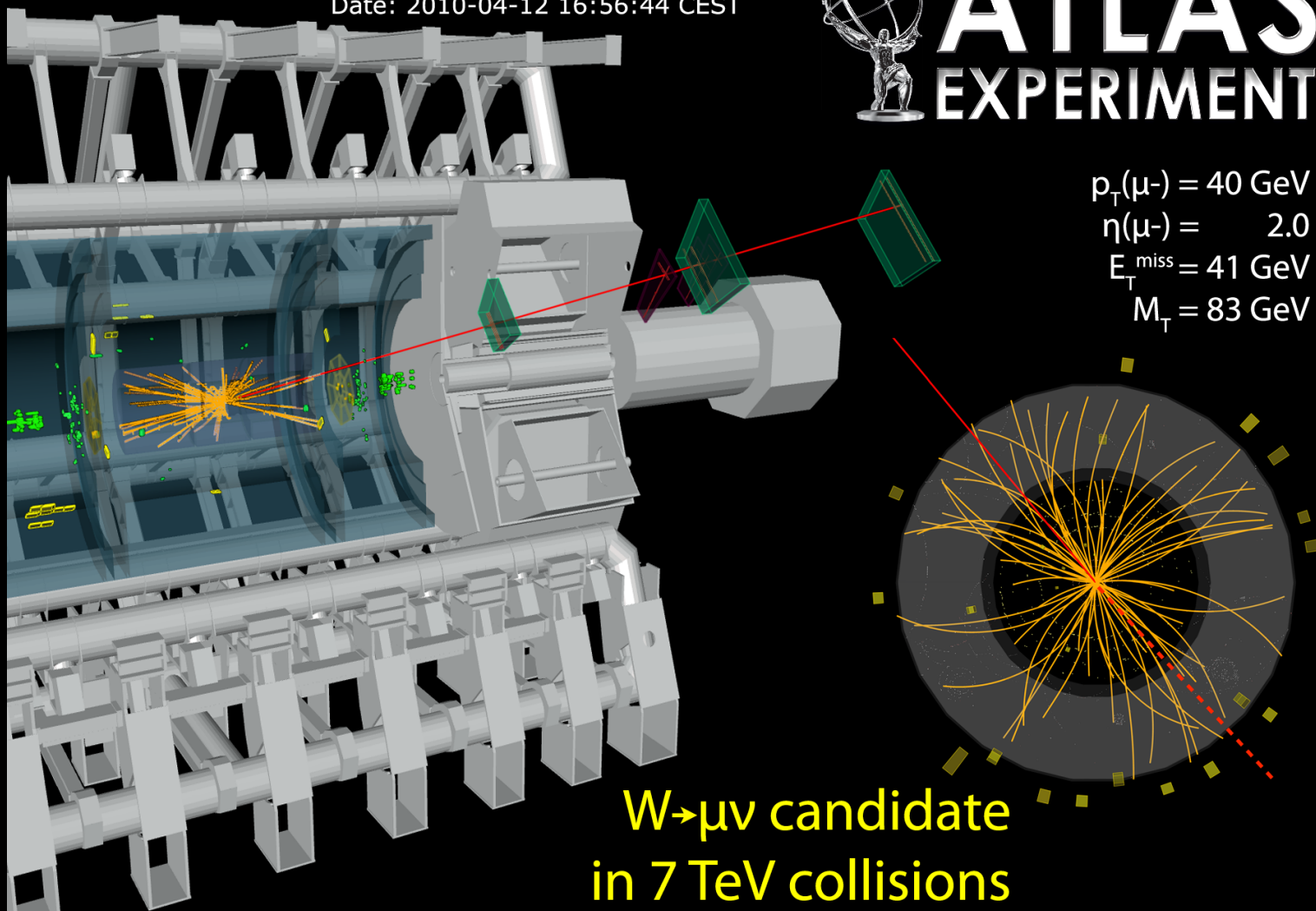
$$W \rightarrow \mu \nu_\mu$$

Run: 152845, Event: 3338173  
Date: 2010-04-12 16:56:44 CEST



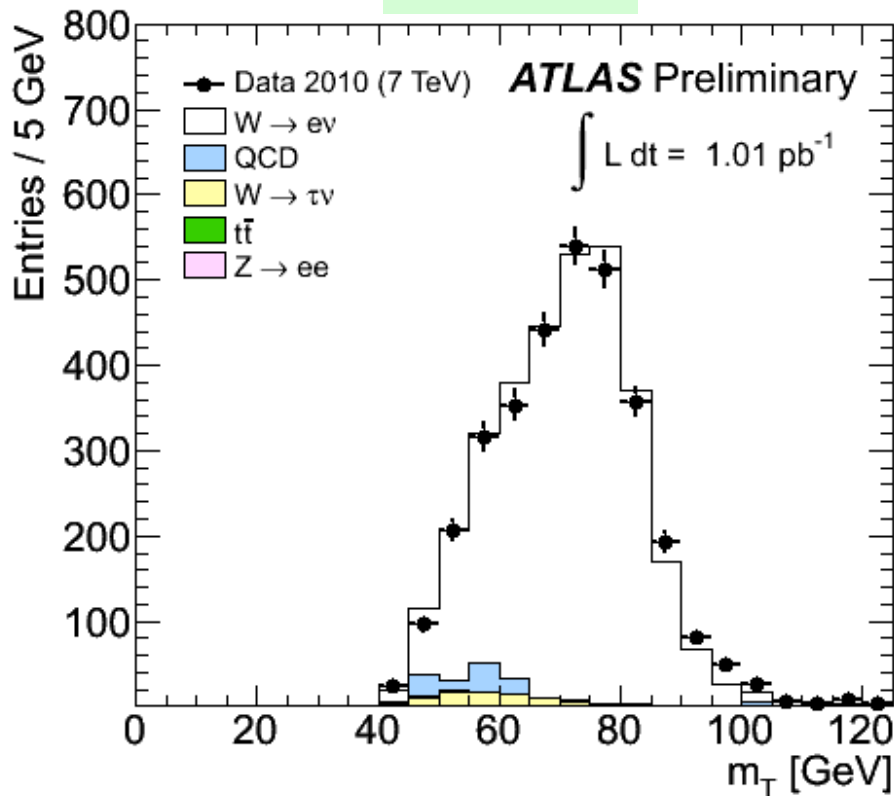
**ATLAS**  
EXPERIMENT

$p_T(\mu^-) = 40 \text{ GeV}$   
 $\eta(\mu^-) = 2.0$   
 $E_T^{\text{miss}} = 41 \text{ GeV}$   
 $M_T = 83 \text{ GeV}$

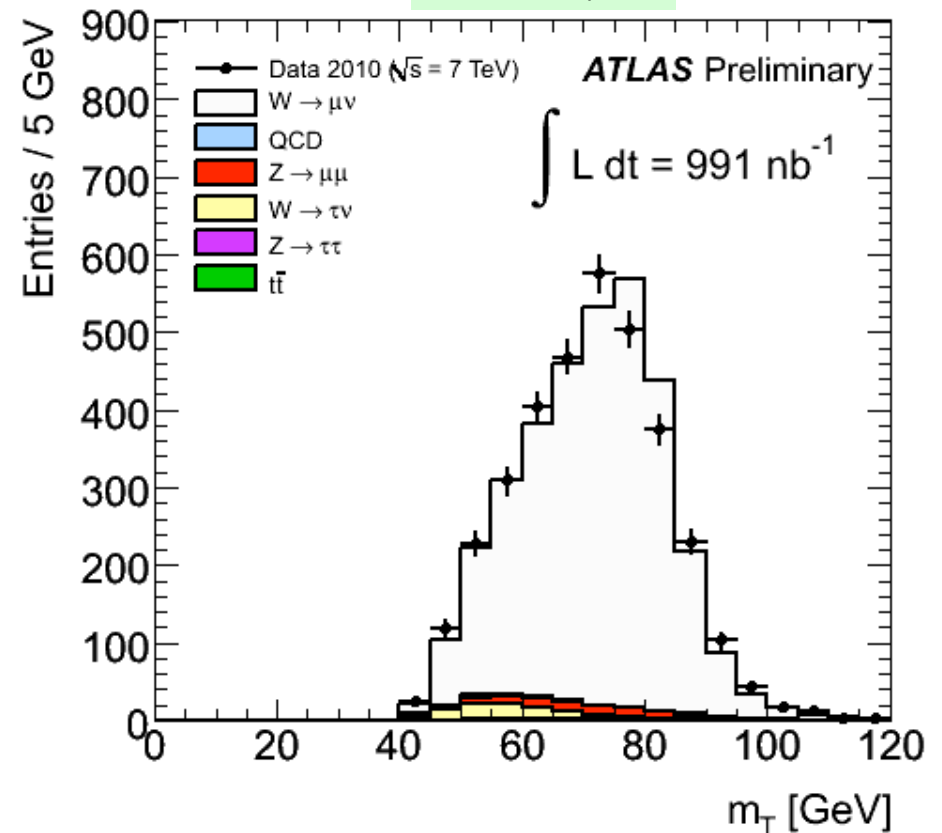


# W's

W → eν



W → μν



- $p_T(e/\mu) > 20$  GeV (isolated),  $E_T^{\text{miss}} > 25$  GeV,  $m_T > 40$  GeV
  - about 3000 candidates/lepton type in  $\int L dt = 1 \text{ pb}^{-1}$
- Data well modeled by simulation

$$Z \rightarrow e^+ e^-$$

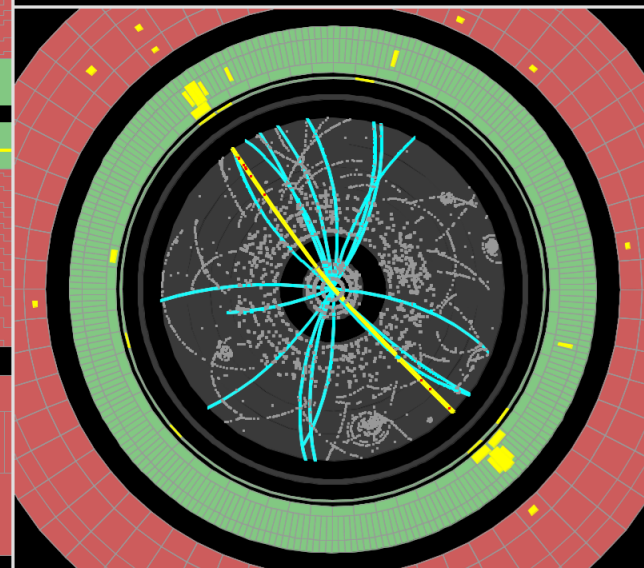
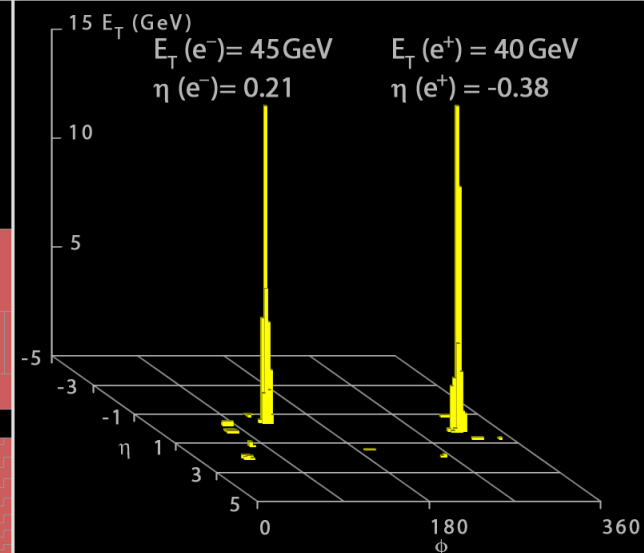
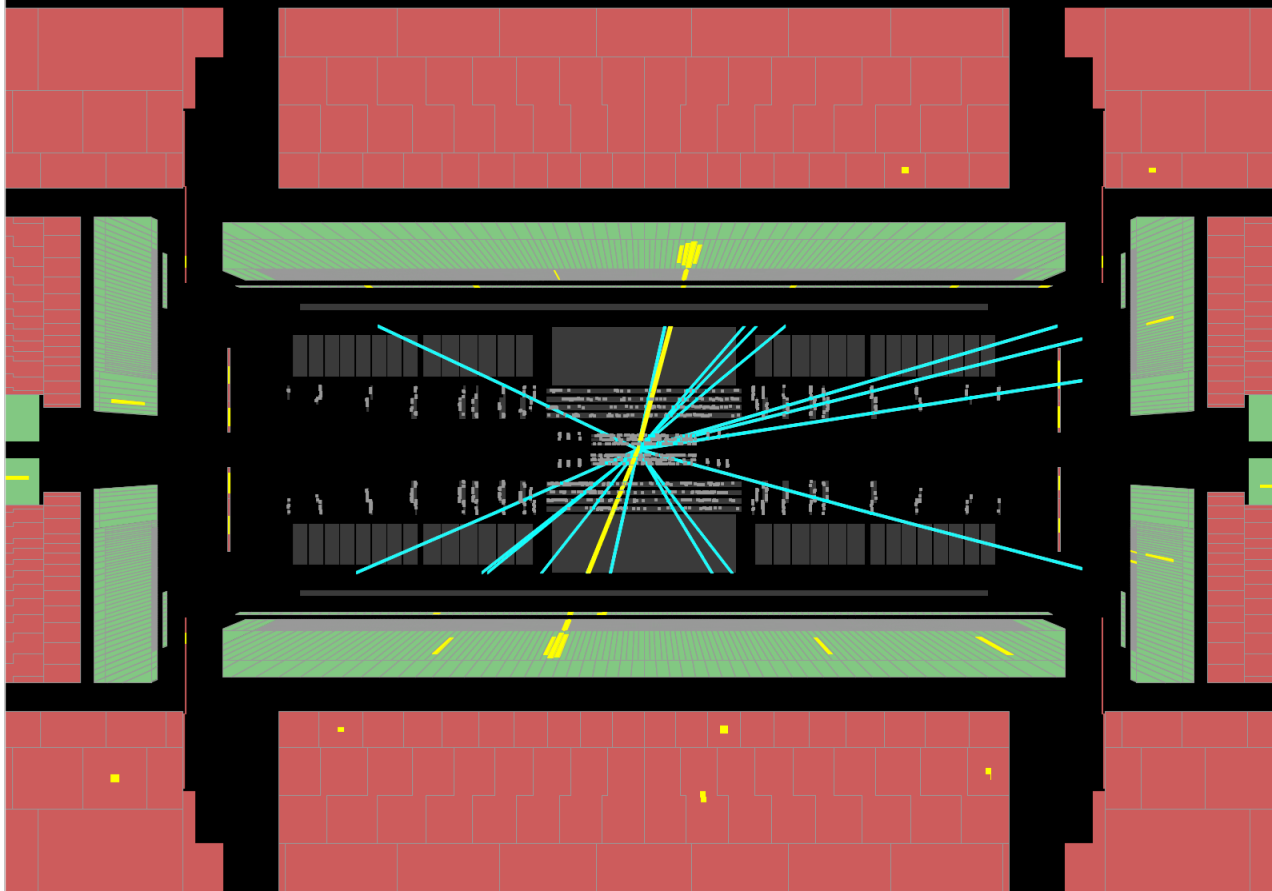


Run Number: 154817, Event Number: 968871

Date: 2010-05-09 09:41:40 CEST

$M_{ee} = 89 \text{ GeV}$

$Z \rightarrow ee$  candidate in 7 TeV collisions

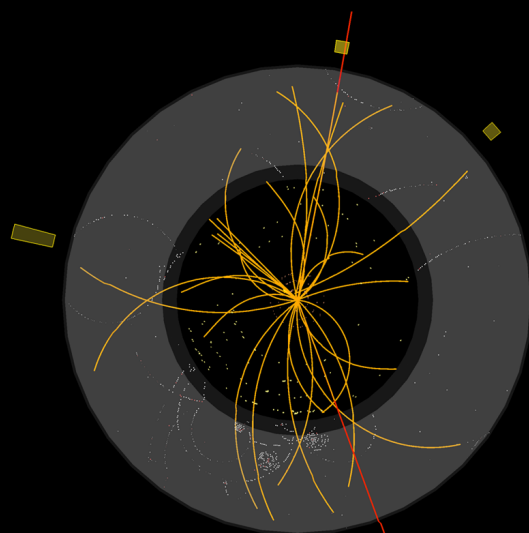


$$Z \rightarrow \mu^+ \mu^-$$



# ATLAS EXPERIMENT

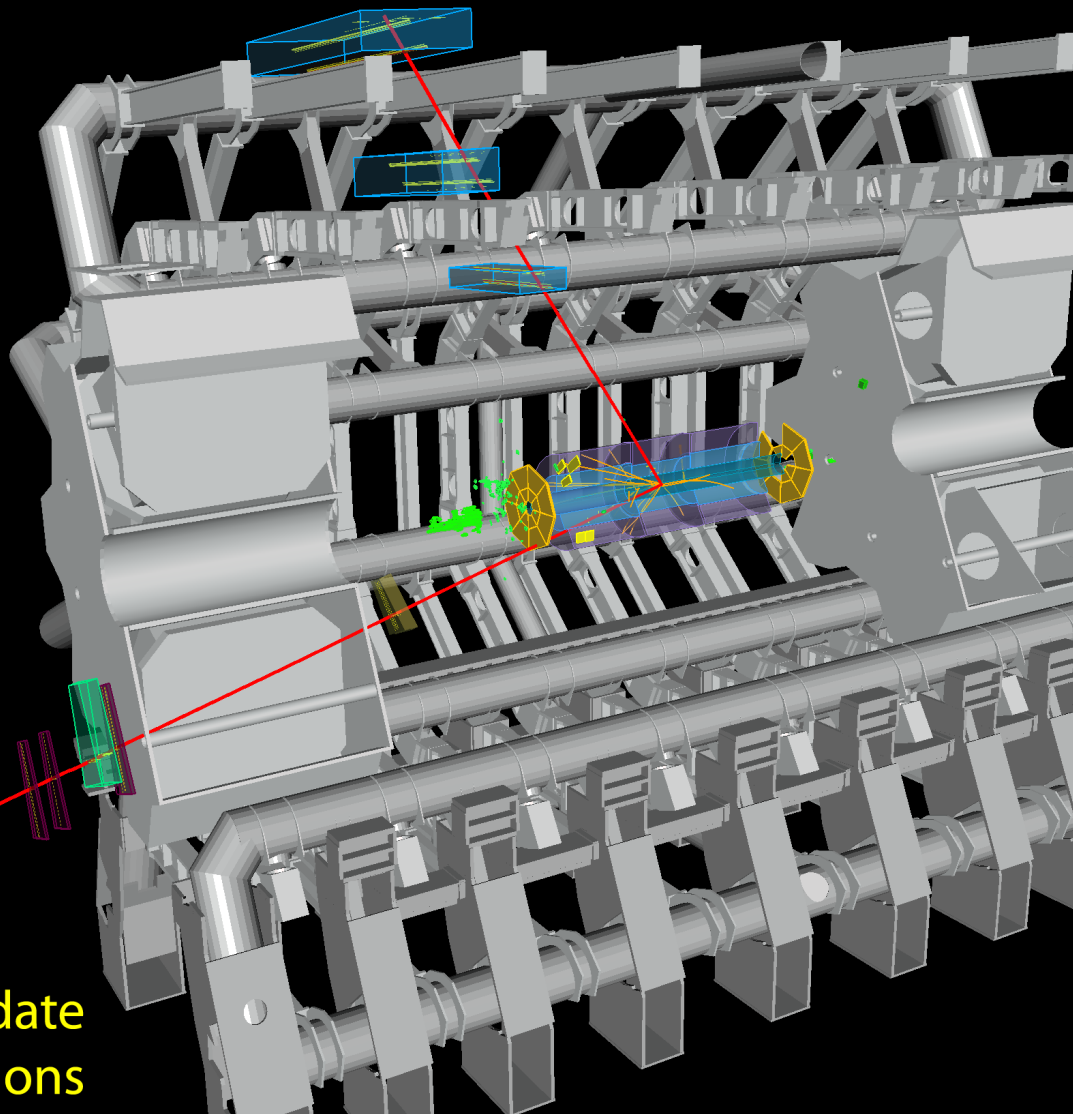
Run: 154822, Event: 14321500  
Date: 2010-05-10 02:07:22 CEST



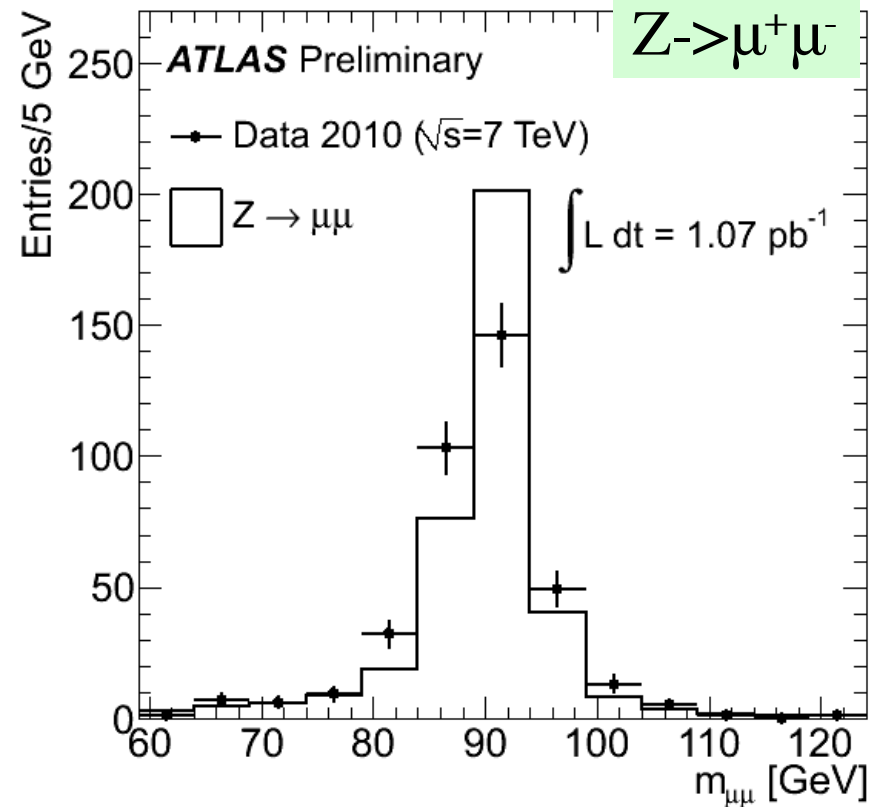
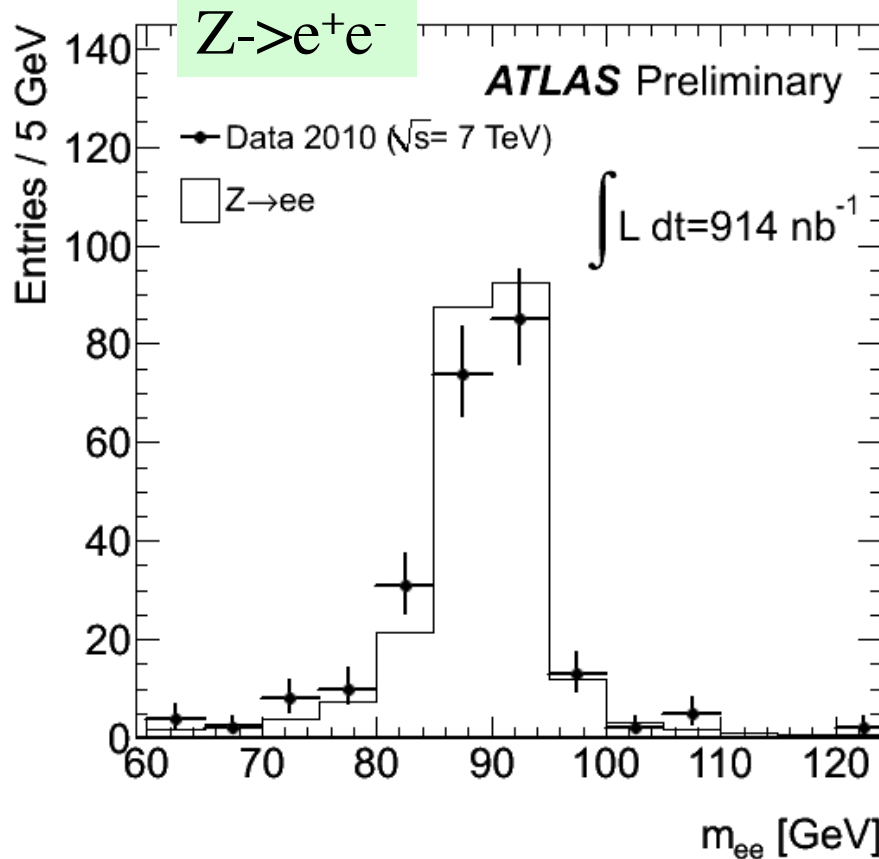
$p_T(\mu^-) = 27 \text{ GeV}$   $\eta(\mu^-) = 0.7$   
 $p_T(\mu^+) = 45 \text{ GeV}$   $\eta(\mu^+) = 2.2$   
 $M_{\mu\mu} = 87 \text{ GeV}$



$Z \rightarrow \mu\mu$  candidate  
in 7 TeV collisions



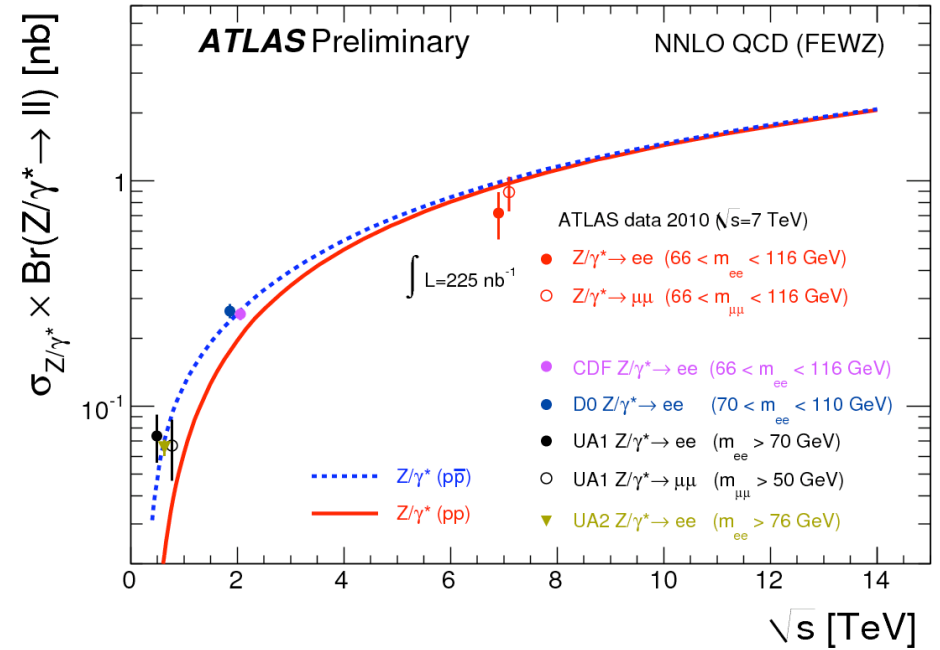
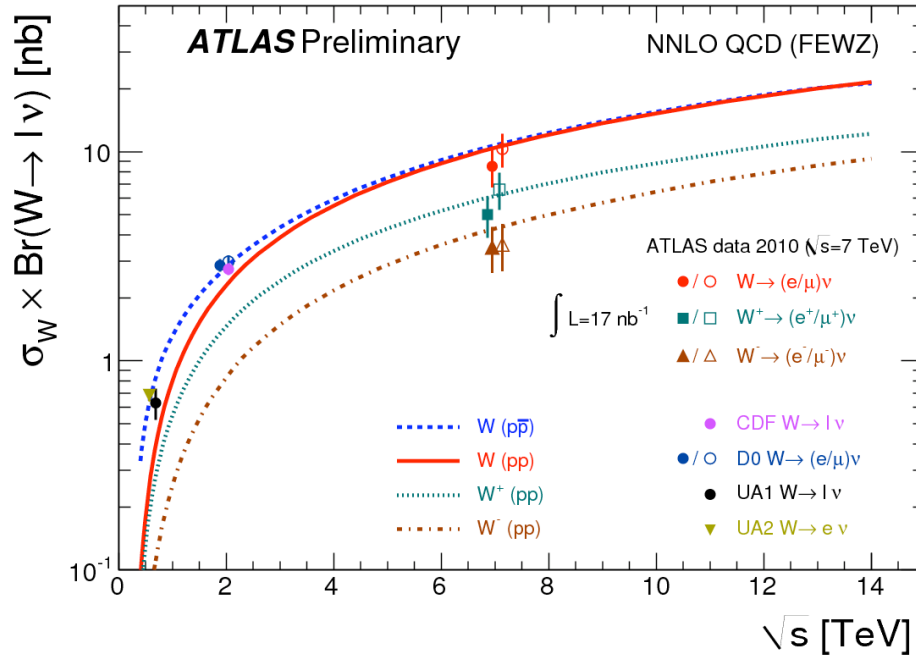
# Z's



- Two leptons with  $p_T > 20$  GeV
  - About 200 (300) Z candidates in  $e^+e^-$  ( $\mu^+\mu^-$ ) channel in  $\sim 1 \text{ pb}^{-1}$
  - Very precious for detector calibration
- Resolution in data slightly worse than simulation
  - Calibration and/or alignment efforts ongoing

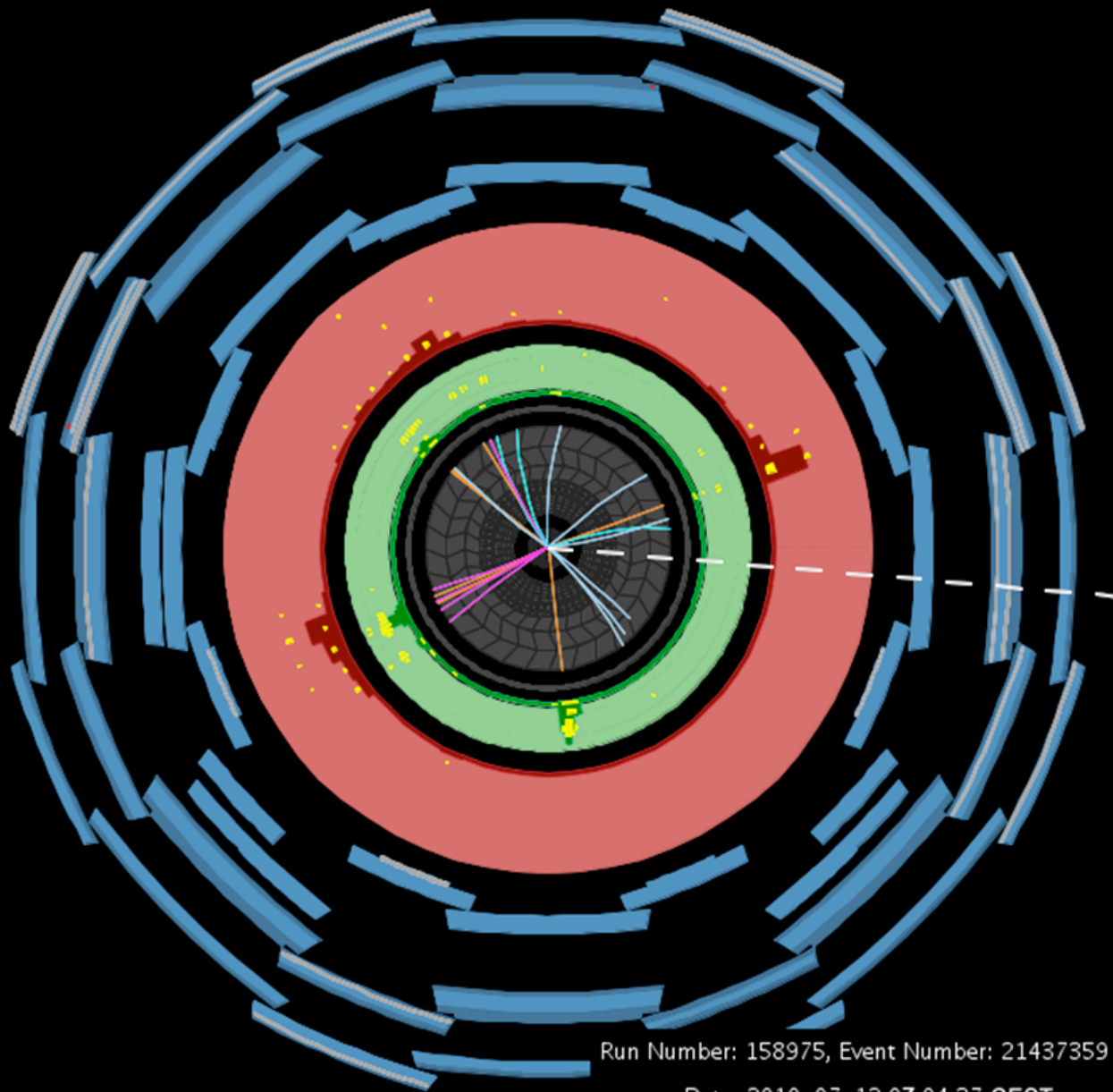


# W and Z Cross Section



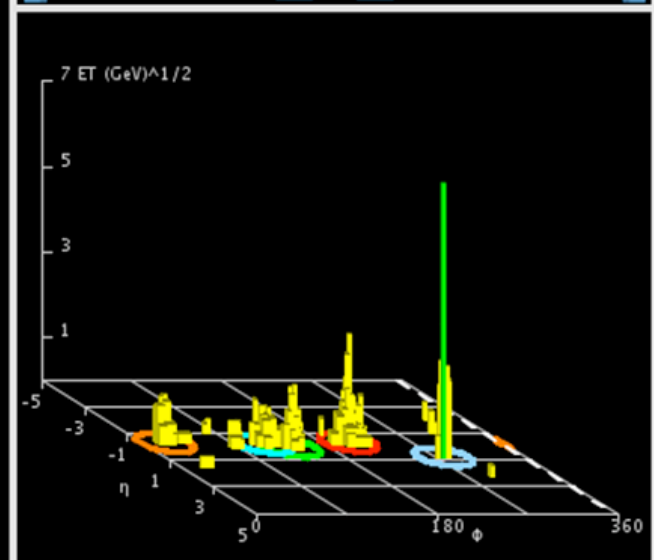
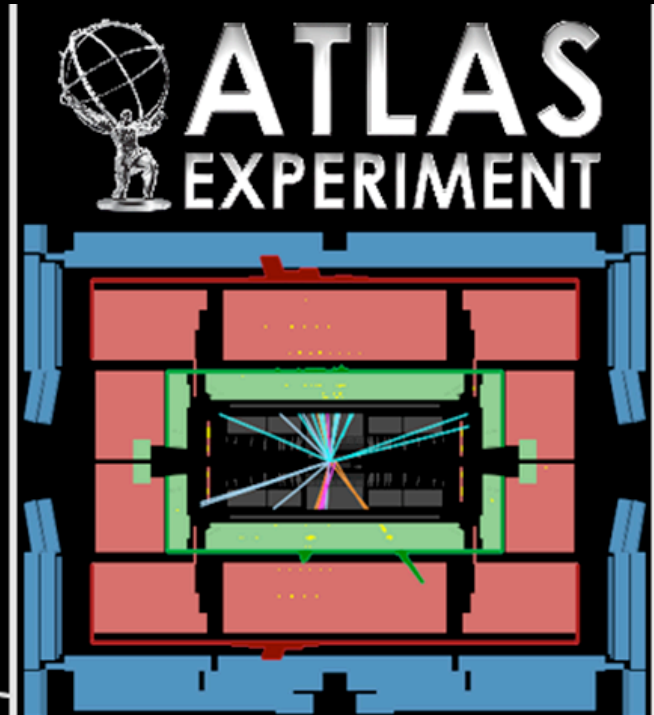
Process	Data	Background	L (nb <sup>-1</sup> )	Cross Section (nb)
W→ev	46	2.6±0.4	17	8.5 ± 1.3 (stat) ± 0.7 (syst) ± 0.9 (lum)
W→μν	72	5.3±0.7	17	10.3 ± 1.3 (stat) ± 0.8 (syst) ± 1.1 (lum)
Z→ee	46	0.49±0.09	219	0.72 ± 0.11 (stat) ± 0.10 (syst) ± 0.08 (lum)
Z→μμ	79	0.17±0.01	229	0.89 ± 0.10 (stat) ± 0.07 (syst) ± 0.10 (lum)

# Towards the Top Quark



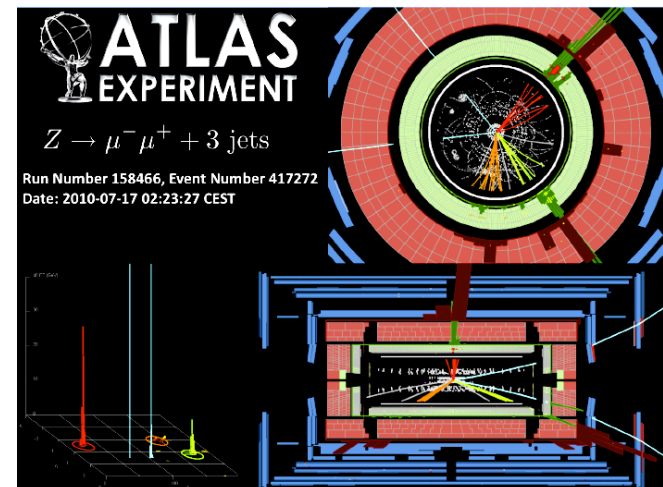
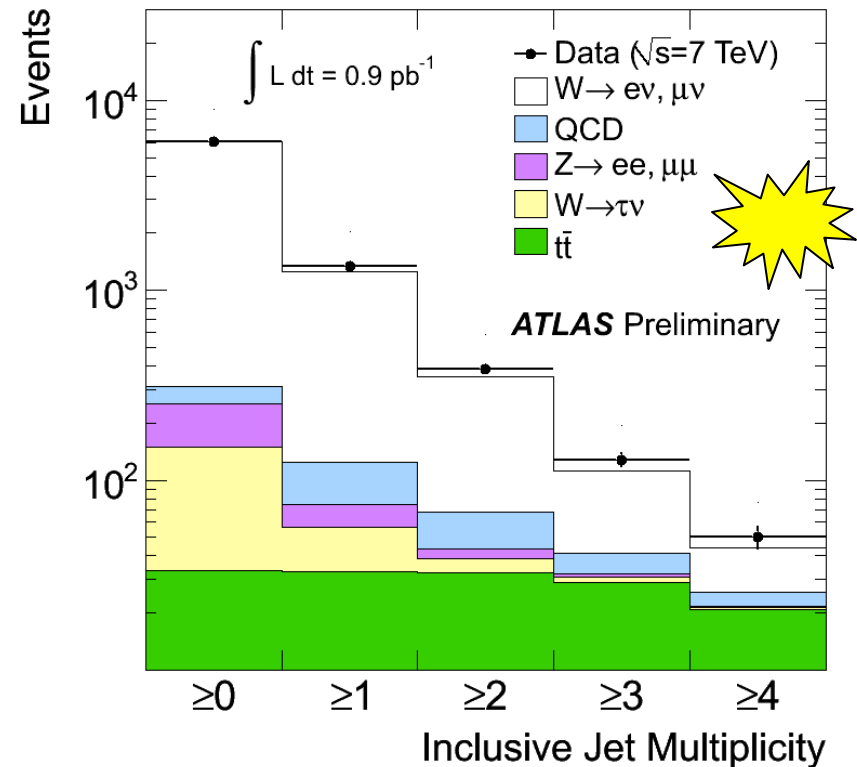
Run Number: 158975, Event Number: 21437359

Date: 2010-07-12 07:04:37 CEST



# W and Z+jets

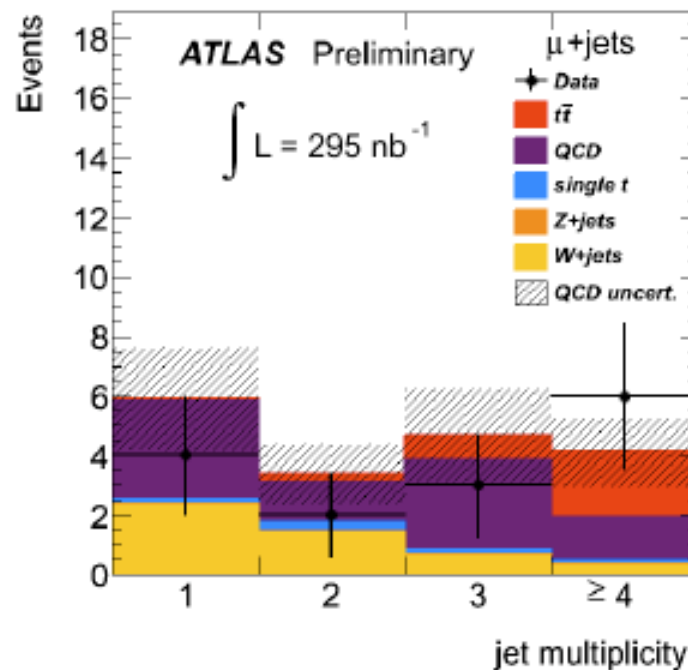
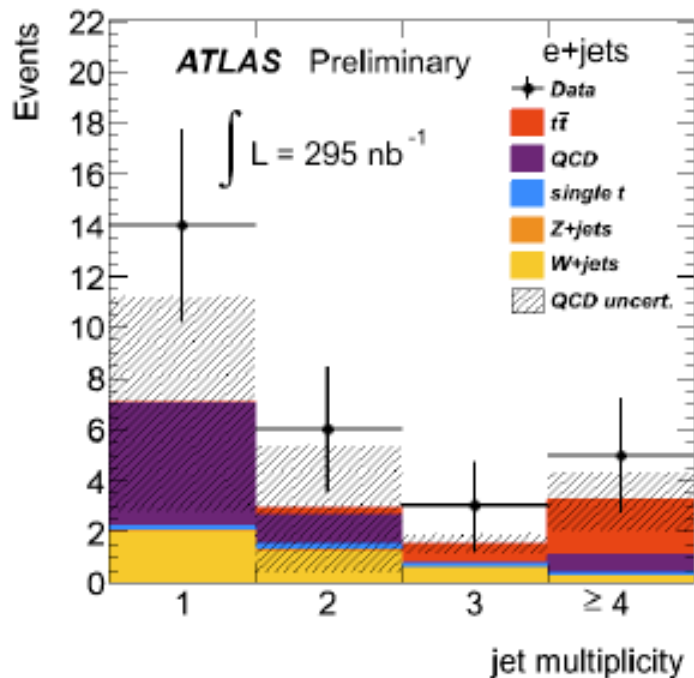
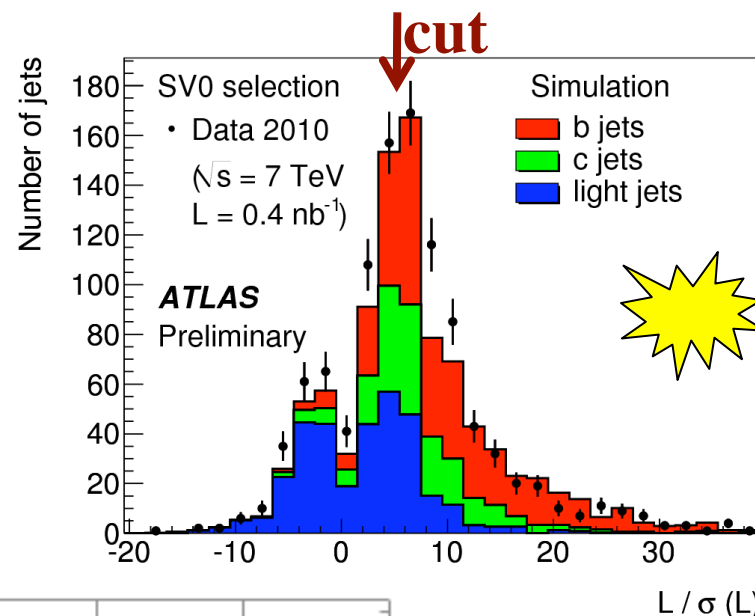
- Major backgrounds to top and New Physics searches (e.g. SUSY)
- Raw  $N_{\text{jet}}$  spectrum agrees well with MC (Alpgen+Herwig)
  - Already  $\sim 100$  W+3-jet events in  $1 \text{ pb}^{-1}$  of data
- Looking forward to corrected cross sections to be compared with NLO QCD predictions
  - E.g. recent predictions by BLACKHAT collaboration



Similar result available for Z+jets

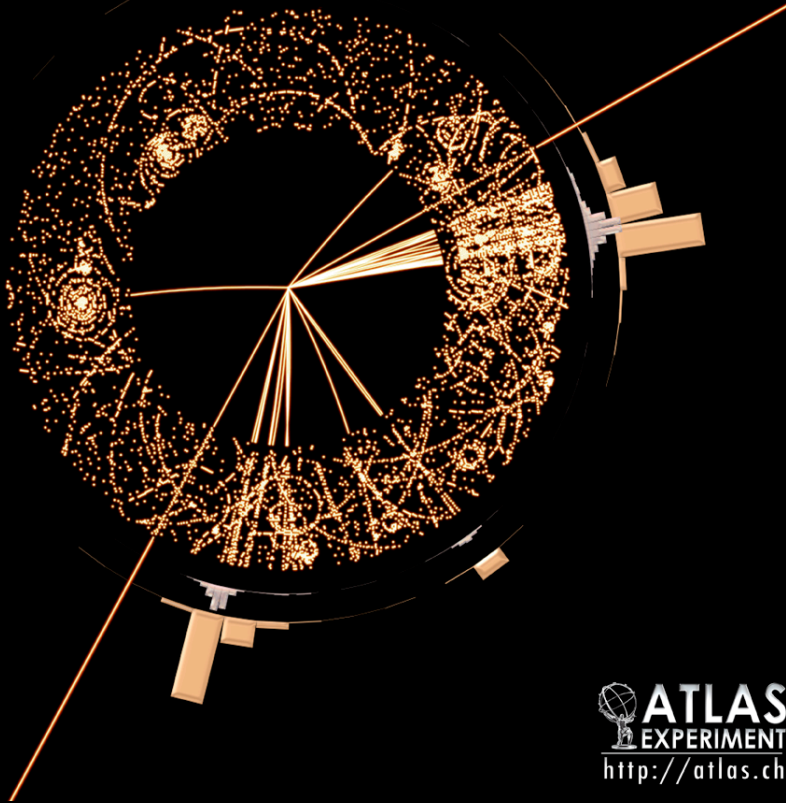
# Towards the Top Quark

- Theoretical cross section: 160 pb
- $p_T(e/\mu) > 20$  GeV,  $E_T^{\text{miss}} > 20$  GeV
- 4 jets ( $p_T > 20$  GeV), at least one b-tagged
  - B-tag based on secondary vertex
  - Decay length significance well modeled: require  $L/\sigma(L) > 5.7$
- In  $0.3 \text{ pb}^{-1}$ : observe 11 events



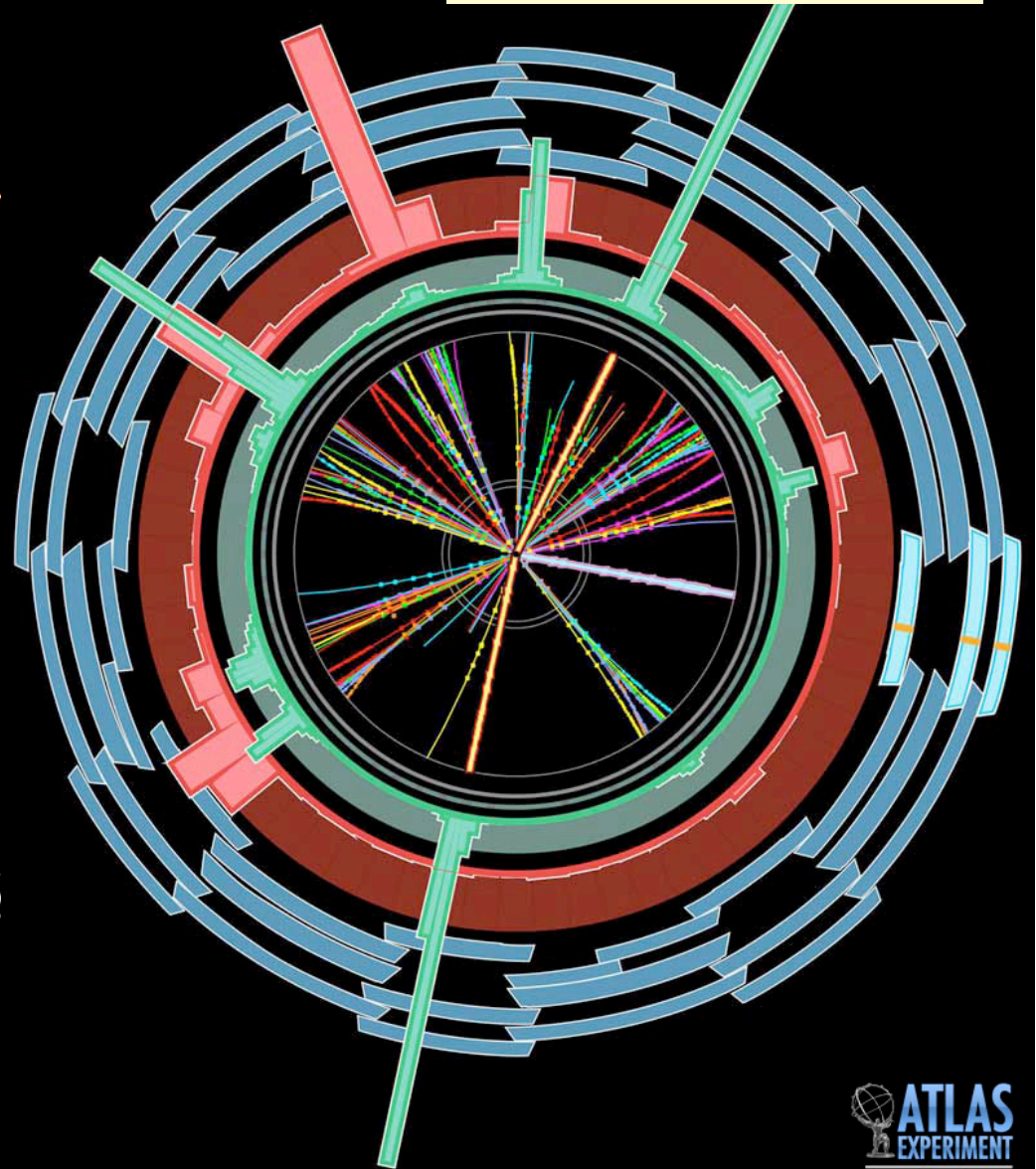
# New Physics

*Supersymmetry*



 **ATLAS**  
EXPERIMENT  
<http://atlas.ch>

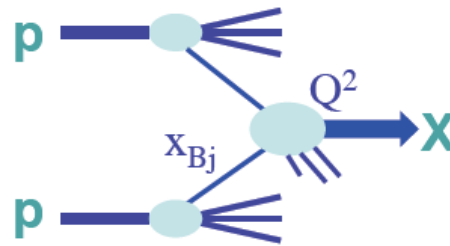
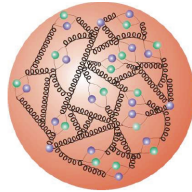
*Micro Black Hole*



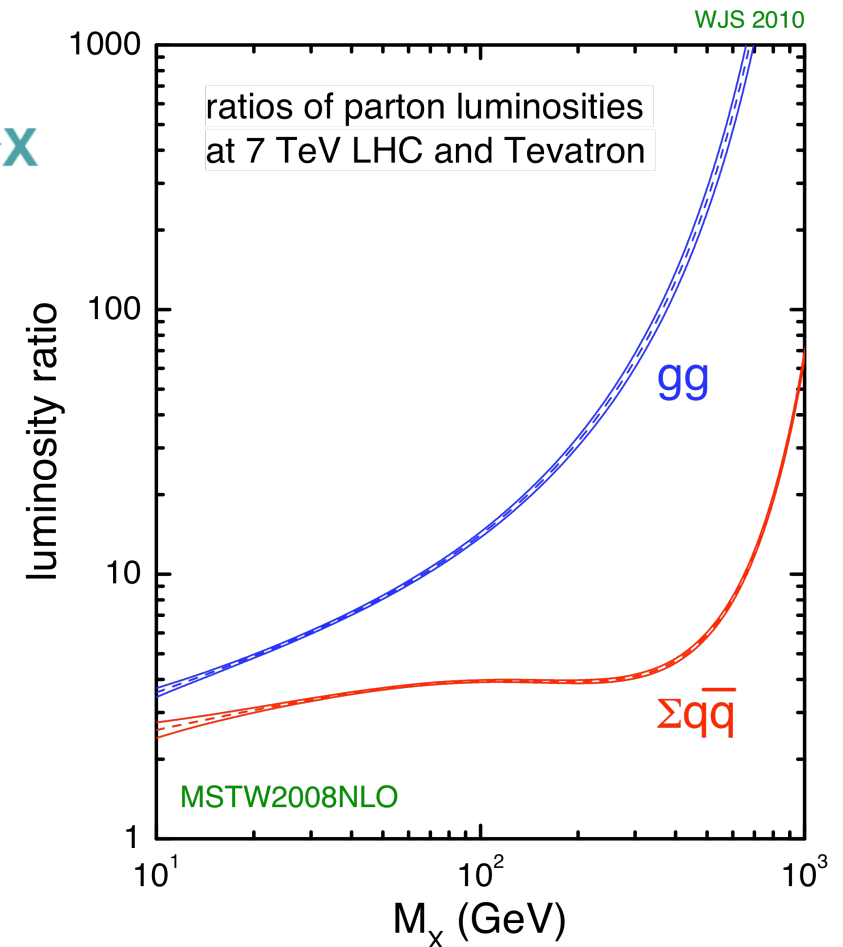
 **ATLAS**  
EXPERIMENT  
<http://atlas.ch>

# New Physics Potential

$$M_X = \sqrt{x_1 \cdot x_2 \cdot s}$$



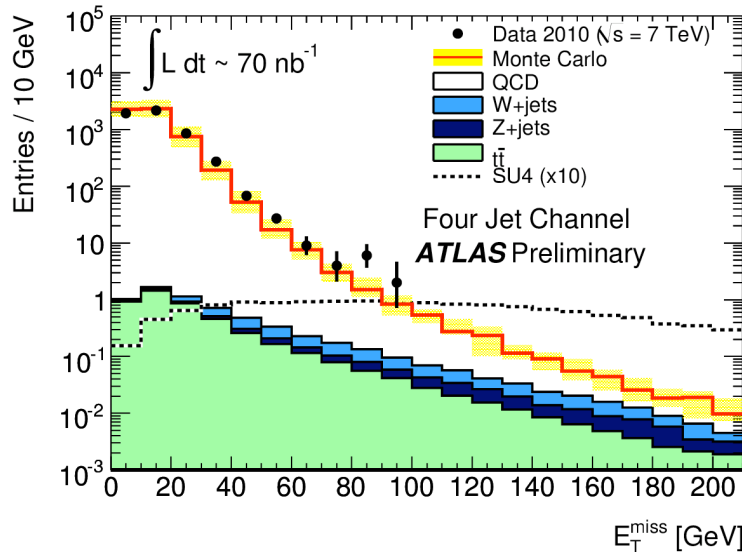
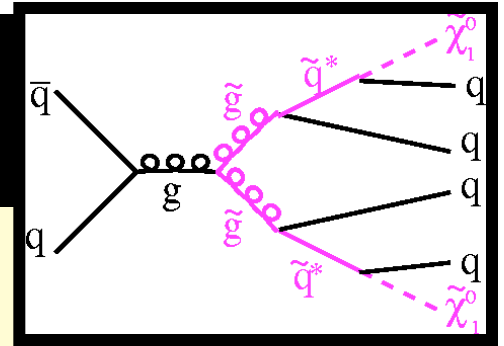
Process	$M_X$	$\frac{\sigma(\text{LHC @ 7 TeV})}{\sigma(\text{Tevatron})}$
$q\bar{q} \rightarrow W$	80 GeV	3
$q\bar{q} \rightarrow Z'_{\text{SM}}$	1 TeV	50
$gg \rightarrow H$	120 GeV	20
$q\bar{q}/gg \rightarrow t\bar{t}$	2x173 GeV	15
$gg \rightarrow \tilde{g}\tilde{g}$	2x400 GeV	1000



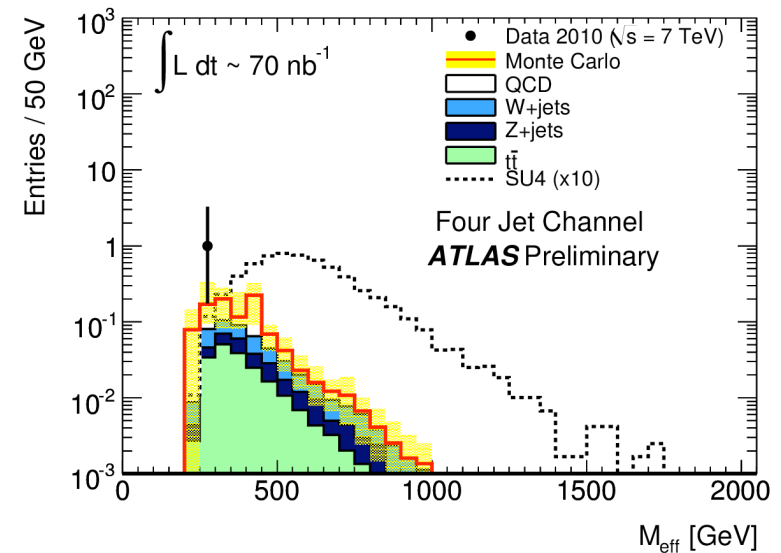
- $\int L dt = 1 \text{ fb}^{-1}$  at LHC competitive with  $10 \text{ fb}^{-1}$  at Tevatron for many high mass processes
  - Already competing now for some new physics scenarios though!

# Supersymmetry Searches

4 jets+0 leptons,  $p_T^1 > 70$  GeV,  $p_T^{2,3,4} > 30$  GeV



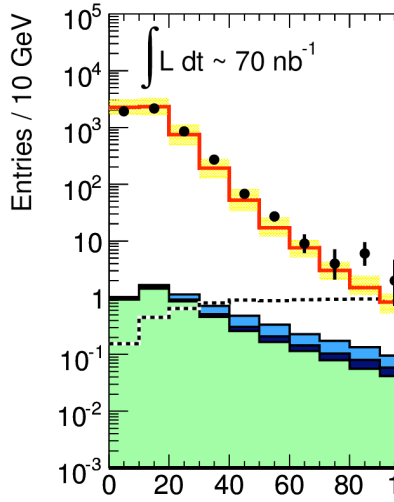
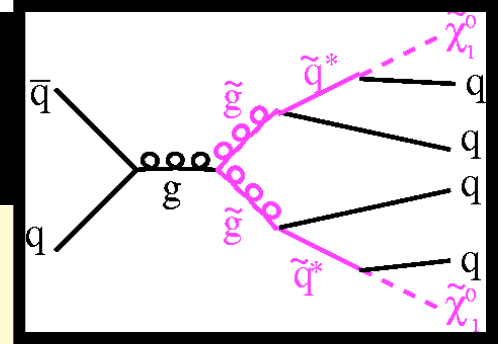
- $E_T^{\text{miss}} > 40$  GeV
- $d\phi(E_T, p_T^{\text{jet}}) > 0.2$
- $E_T/M_{\text{eff}} > 0.2$



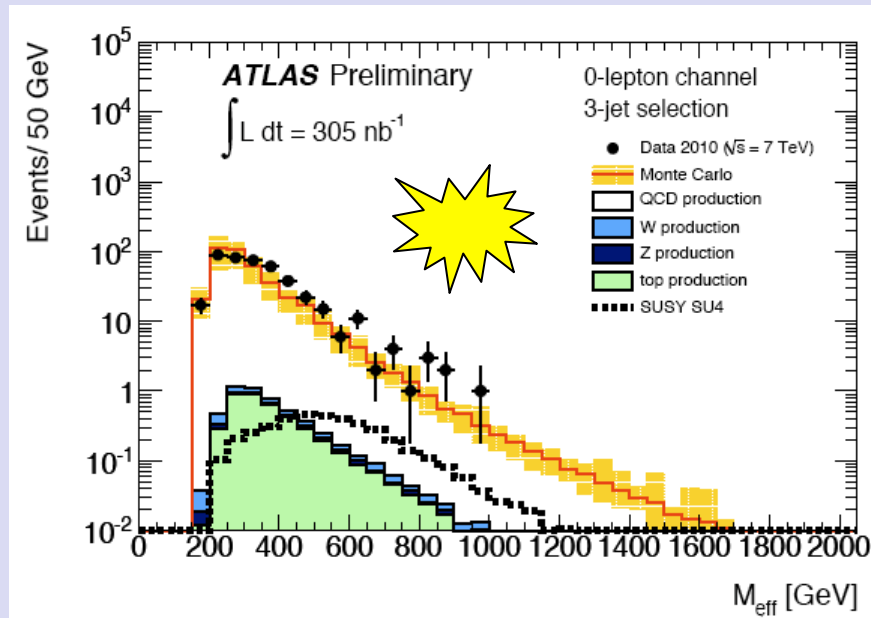
- Data consistent with background
  - Excellent control of missing  $E_T$
- Possibly sensitive beyond Tevatron for non-mSUGRA type models already
  - Alvez, Izaguirre, Wacker: arXiv:1008.0407

# Supersymmetry Searches

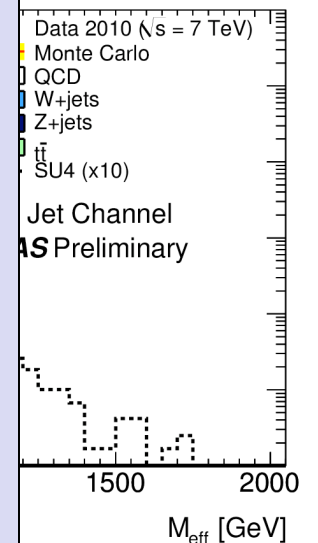
4 jets+0 leptons,  $p_T^1 > 70$  GeV,  $p_T^{2,3,4} > 30$  GeV



- 0 leptons, 3 jets,  $\geq 1$  b-tag
- $p_T^1 > 70$  GeV,  $p_T^{2,3} > 30$  GeV
- $E_{T}^{miss} / \sqrt{\Sigma E_T} > 2 \sqrt{\text{GeV}}$

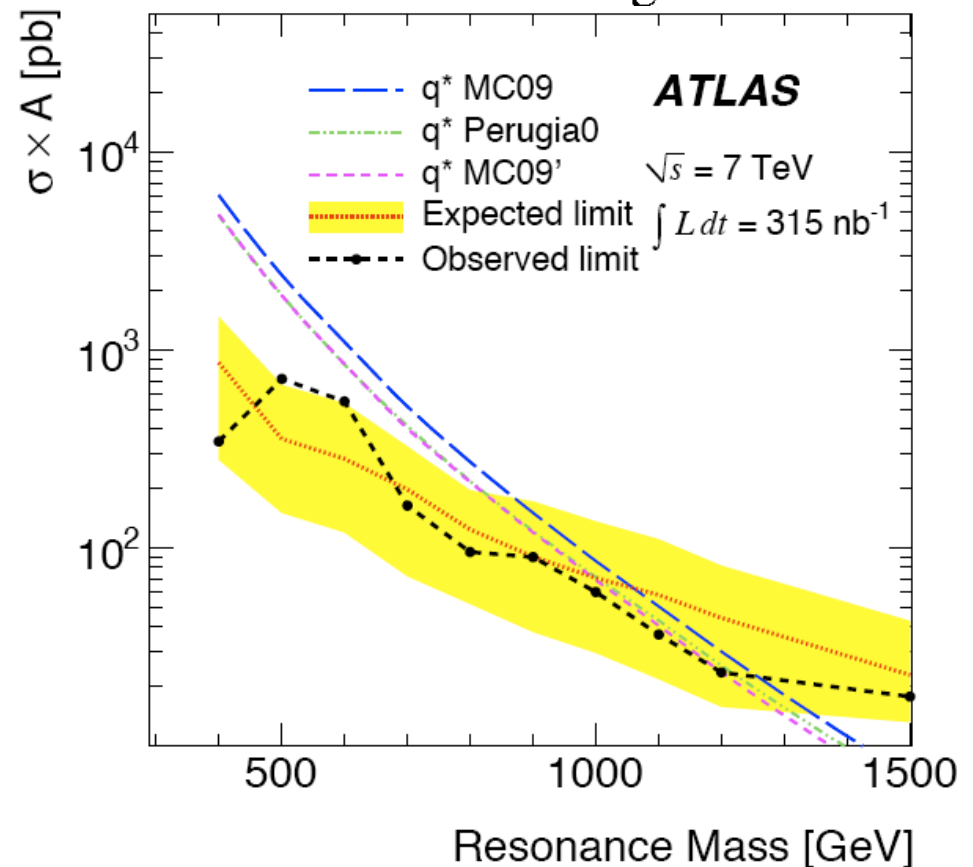
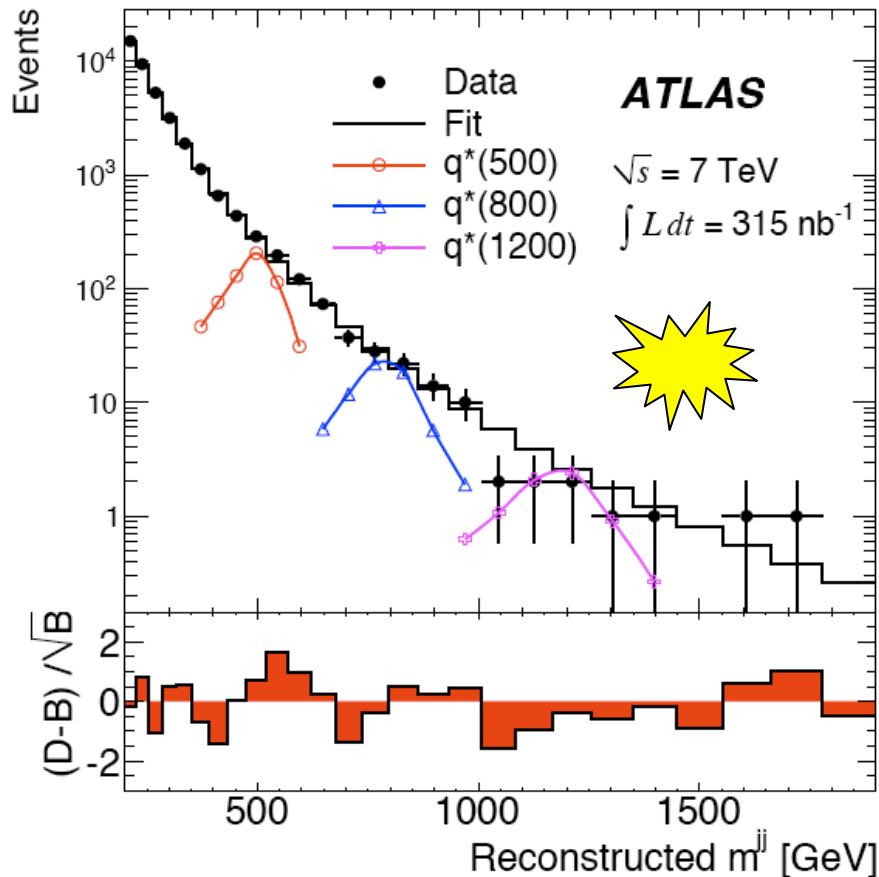
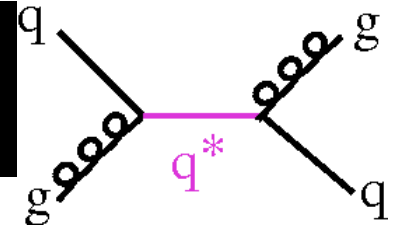


First steps towards 3<sup>rd</sup> generation squarks



- Data consistent with SM
- Excellent agreement with SM
- Possibly sensitive to new physics
- Tevatron for squarks
- models already excluded
- Alvez, Izaguirre

# Dijet Resonance: $q^*$

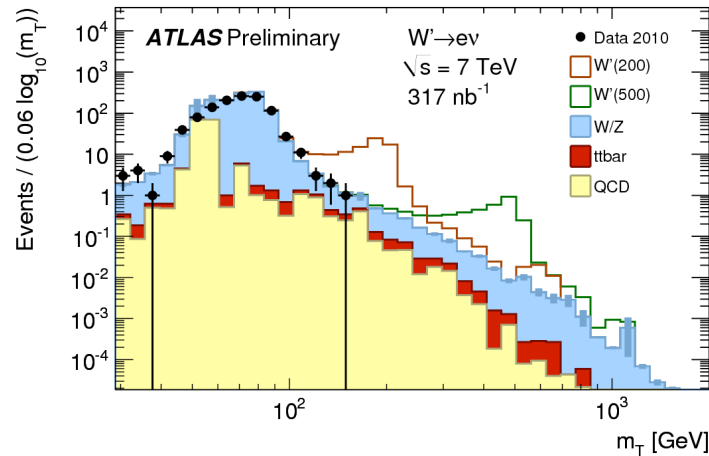


- $p_T^{\text{jet1}} > 80 \text{ GeV}$ ,  $p_T^{\text{jet2}} > 30 \text{ GeV}$ ,  $|\eta^{\text{jet1}} - \eta^{\text{jet2}}| < 1.3$
- No evidence for peak in dijet mass spectrum
- Constrain  $m(q^*) > 1.26 \text{ TeV}$ 
  - Supersedes published CDF limit of 0.87 TeV (with  $1 \text{ fb}^{-1}$ )

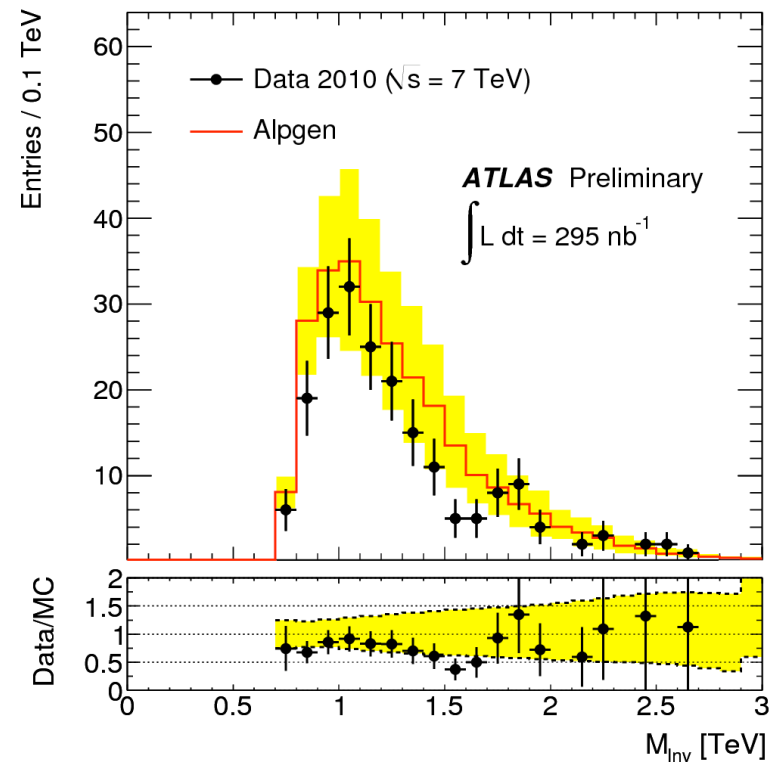
*arXiv: 1008.2461  
 submitted to PRL*

# More Searches for New Physics

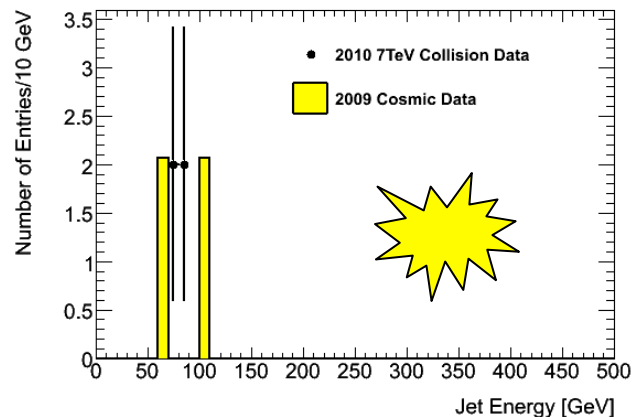
## Search for $W'$ bosons



## Search for high-multiplicity events (as expected from micro-Black Hole)



## Background study to search for “R-hadrons” in empty bunches (split-SUSY,...)



# Conclusions and Outlook

- **The LHC era has started**
  - LHC performance remarkable *and* improving week by week
    - On track for  $1 \text{ fb}^{-1}$  in 2011
  - ATLAS is efficiently taking high quality
- **ATLAS has made many physics measurements**
  - Thanks to excellent performance of detector, simulation, reconstruction, data distribution (grid) ... and many many people!
  - Major contributions to many aspects by US west coast
- **If Nature is kind LHC experiments can find something in 2010/2011**



# How to get to 1 fb<sup>-1</sup>?

	LHC (now)	LHC (end of 2010)	LHC (design)
$\sqrt{s}$ [TeV]	7	7	14
# of colliding bunches	Up to 35	384	2808
Protons/bunch [ $10^{10}$ ]	10	10	11.5
Energy stored (MJ)	2.7	21.5	362
Peak Luminosity [cm <sup>-2</sup> s <sup>-1</sup> ]	$1 \times 10^{31}$	$\sim 1 \times 10^{32}$	$10^{34}$
Integrated Luminosity	3 pb <sup>-1</sup>	$\sim 40$ pb <sup>-1</sup> (?)	10-100 fb <sup>-1</sup> /yr

(\* plan constantly adjusted in reaction to what is learned)

- In following weeks
  - **Increase number of bunches each week by factor ~2**
    - Involves using “bunch trains”: 150ns separation between collisions
- 2011
  - Further focus the beam ( $\beta^*$ : 3.5m => 2m)
  - Deliver  $\int L dt = 1 \text{ fb}^{-1}$  (requires e.g. 30% LHC up-time at  $1.5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ )